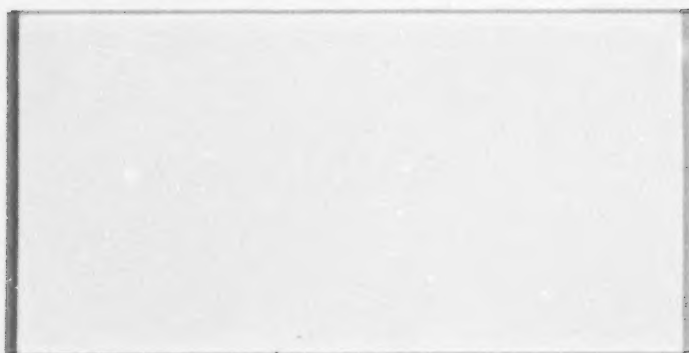


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LABORATORY STUDIES OF FISH
RESPONSE TO POROUS INTAKES
AND A ROPE NET BARRIER - 1982

Report No. 83-351-K

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ABSTRACT

Responses of alewife, smelt and yellow perch to full-scale segments of porous (PPB) intakes and rope net barriers were tested in a laboratory model during daylight, twilight and darkness. Incremental velocity tests (daylight only) indicated that perch vulnerability to capture by the PPB intake did not increase sharply until velocities exceeded 30 cm/s (design maximum). Alewife (tested up to 60 cm/s) were less vulnerable than perch to increased velocity. Differences in total capture and capture/encounter percentages between flush port and projecting port PPB intakes were minor and did not consistently favour either surface. In comparative tests using alewife, the porous intake produced better average results than the low velocity rope net (capture: 26.1% versus 29.5%; capture/encounter: 3.2% versus 7.7%). In smelt tests, the PPB captured 42.8%, the low velocity rope net captured 52.0% and the high velocity rope net captured 57.0%. Capture/encounter percentages were 5.2%, 14.9% and 12.9%, respectively. In perch tests, the PPB caught 46.4% of fish tested, the low velocity rope net caught 39.2% and the high velocity rope net caught 73.1%. Yellow perch capture/encounter percentages were 18.8%, 29.2% and 7.5%, respectively. For protection of pelagic species (alewife, smelt) the PPB intake is recommended as the preferred alternative to a velocity cap intake equipped with a rope net barrier.

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To Dr. W.R. Effer
Manager
Environmental Studies and Assessments

LABORATORY STUDIES OF FISH RESPONSE TO POROUS VENEER INTAKES AND A ROPE NET BARRIER - 1982

J.S. Griffiths

1.0 INTRODUCTION

1.1 Study Objective

This report describes laboratory studies conducted at the request of the Environmental Studies and Assessments Department to evaluate the effectiveness of a new intake design, the pre-cast porous bottom (PPB) type, in reducing entrapment of Great Lakes fish. The project (ES&A work package EPP-820-09909-82/2) is part of the ongoing Capitalized Once-Through Cooling (COTC) Program. In addition to testing of the porous intake, comparisons were also made with a behavioral barrier (coarse rope net) suitable for retrofit to existing velocity cap intake designs.

Initial laboratory tests of the porous intake were conducted in 1981 at the request of ES&A (work package 820-09909, Ontario Hydro Research Division Report in preparation, J.S. Griffiths). In that study, fish were tested with a full scale segment (2 m diameter) of a porous intake operating at prototype velocities of approximately 15 cm/s through the intake ports.

Tests were run under low level daylight (approximately 10 lux) and twilight (10^{-3} to 10^{-4} lux) using two pelagic schooling species (smelt, alewife) and two benthic species (yellow perch, pumpkinseed sunfish). Four different manufactured intake surfaces and a natural stone veneer were tested. Fish were able to avoid entrainment with all intake surfaces, despite repeated encounters with the intake flow. A very small number of fish was entrained when the intake surface was removed.

The 1982 laboratory studies were designed to determine the effect of increasing both the velocity of the intake flow and the size of the intake surface. Due to time limitations only alewife and yellow perch were used for tests. Two intake surfaces (flush and projecting intake ports) plus an open intake control were used for these experiments. Daylight, twilight and dark tests were run. During the study, ES&A also requested that a comparison be made between the precast porous bottom (PPB) intake and a coarse rope barrier suitable for retrofit to a velocity cap intake. This comparison was done under conditions of daylight, twilight, and complete darkness. Test species were alewife (Alosa pseudoharengus), rainbow smelt (Osmerus mordax) and yellow perch (Perca flavescens).

1.2 Background

The once-through cooling process presently used at Ontario Hydro's large multi-unit thermal generating stations requires very large volumes of cooling water. For example, at Darlington GS, a 3500 MW nuclear station presently under construction on Lake Ontario, the cooling water flow will range from 150 m³/s in summer to 120 m³/s in winter. The two Bruce generating stations on Lake Huron each use 170 m³/s of cooling water, as these slightly smaller stations operate with a lower temperature rise (ΔT). The capture of large numbers of fish in the cooling water flow has occasionally resulted in interruptions of generating station operation. Bruce GS 'A', Pickering GS 'A' and Lambton GS have all suffered costly unit shutdowns or de-ratings when massive fish impingement has overloaded screening systems in station forebays. Substantial numbers of fish have also been entrapped by the intakes of Nanticoke GS and Lennox GS, although the tendency for fish to be removed from these forebays via tempering water pumps has prevented interruption of station operation.

Most fish captured by cooling water intakes are forage species such as alewife and gizzard shad although some species of commercial value (smelt, yellow perch) are occasionally taken in large numbers (Foster, 1981). Generally, capture of valued sports fish (trout, salmon, bass, pike) has been quite low. Regulatory agencies (Ontario Ministry of the Environment, Ontario Ministry of Natural Resources) have expressed concerns regarding the loss of fish (both chronic and acute impingement episodes) at Ontario Hydro generating stations and have requested that Hydro include fish conservation systems at the cooling water intakes of new generating stations (Bruce GS 'B', Darlington GS). They have also suggested that retrofit systems may be required at other generating stations (Bruce GS 'A', Pickering GS 'A', Nanticoke GS). The Ontario Hydro Once Through Cooling Program recognized fish impingement as the major

environmental concern resulting from Hydro's operation of thermal generating stations (Design and Development Division No 81481).

Present Ontario Hydro submerged intakes are variants of the velocity cap type first installed in 1956 at the Southern California Edison El Segundo Generating Station. The velocity cap intake appeared superior to a simple open pipe intake, as the cap created a horizontal flow which fish seemed better able to perceive than vertical currents (Weight, 1958). Further model testing verified these results and led to an improved version (for SCE San Onofre GS, Units 2 and 3) which featured a somewhat wider cap and an extended lower lip. These additions resulted in a more uniform horizontal flow and were expected (on the basis of laboratory tests) to reduce capture of bottom dwelling fish species (Downs and Meddock, 1974; Schuler and Larson, 1975).

Ontario Hydro Velocity cap intakes (Figure 1) differ somewhat from the SCE intakes. Hydro intakes have not included a bottom lip, as capture of bottom-dwelling fish or invertebrates has not been considered a major problem in the Great Lakes. Flow fields created by the Hydro intakes shown in Figure 1 probably contain substantial vertical components (particularly the Nanticoke style intakes which have small caps). Also, placement of the Bruce type intakes in an excavated basin (to increase protection from wave or ice damage) may have deleterious biological effects, as fish may be less likely to swim around the intake structure. However, the major difference between Ontario Hydro velocity caps (particularly the more recent Bruce type structures) and those of SCE is the total size. The Bruce intakes (Figure 1) have a clear opening between the cap and flotation collar of nearly 10 m, whereas in the San Onofre intake this opening is only about 2 m. Also, the diameter of the Bruce intakes is approximately 2.5 times that of the SCE intakes. It seems likely that Ontario Hydro velocity cap intakes are simply too large to be effective as fish deterrents. Only under the most favourable visibility conditions would entrained fish be able to see the intake structure and take avoidance action prior to being drawn under the cap.

Foster's (1981) television and scanning sonar observations at the Nanticoke GS western intake demonstrate the importance of cueing mechanisms in the avoidance of entrainment by fish. Although Foster noted that substantial vertical flow occurs at this intake, observations of fish being entrained by the intake indicated that the main cause of fish entrapment was not the velocity or direction of flow, but the inability of fish to perceive the intake flow and/or the intake structure. Most fish being entrained by the intake were not taking appropriate

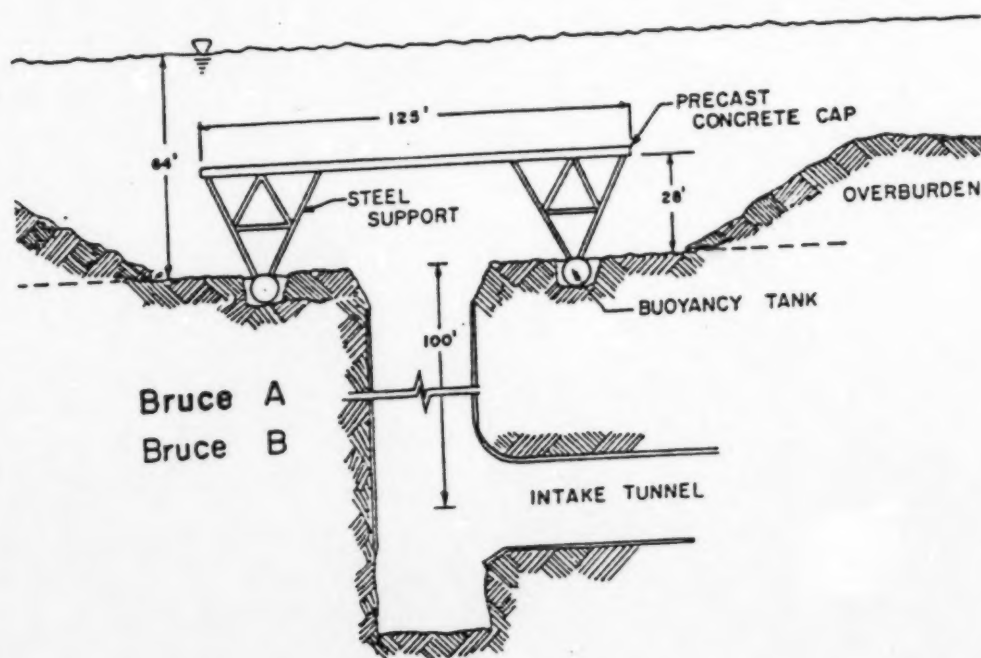
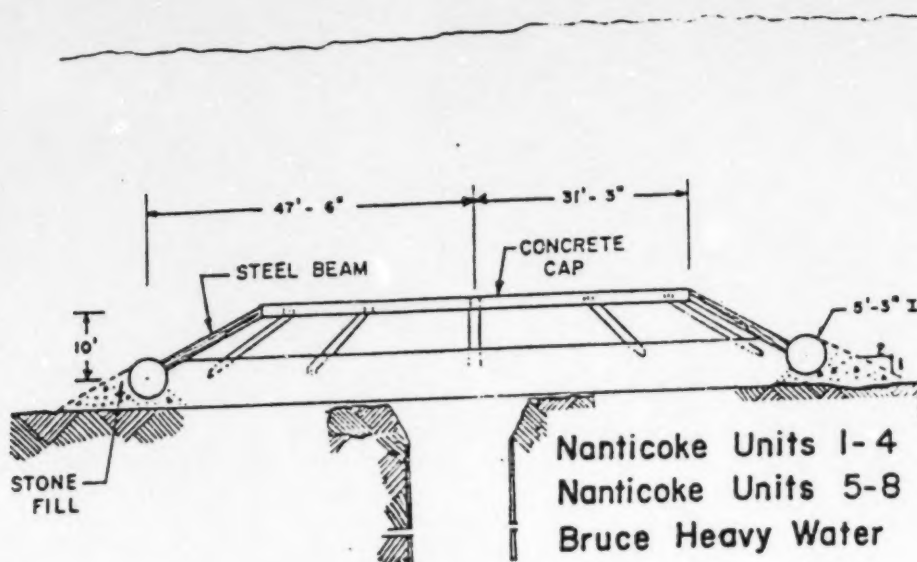


FIGURE 1
ONTARIO HYDRO INTAKES
(FROM MACLAREN, 1975)

avoidance action and were swimming with the current or (more commonly) across the current. Foster suggested that avoidance of capture by the intake was dependent upon the ability of fish to perceive the intake structure visually or to perceive the currents where abrupt changes in direction or velocity occurred near the edge of the intake cap. As entrapment was highest during periods of high turbidity, Foster (1981) suggested that visual perception of the intake was the most important factor affecting capture of fish by the Nanticoke intake. However, capture was lowest (on a unit flow basis) when cooling water flow was highest. Thus, higher flow rates appeared to improve the ability of fish to detect and respond to the intake currents before they were drawn under the intake cap, where poor visibility, the presence of the cap, and rapidly accelerating flows into the intake shaft generally prevented escape.

Foster's observations thus indicate the importance of environmental discontinuities (visual, current) for fish to perceive the entrance to a cooling water intake and take appropriate avoidance action. Failure of velocity cap intakes to prevent fish entrapment appears to be the result of the size of the openings (visual cues absent or obscured by turbidity) and the large, relatively uniform flow field created by these intakes.

The porous intake concept was developed to circumvent the problems of velocity cap intakes described above. The original proposal was for a stone-filled excavation (much like the excavation used for the Bruce intakes) overlying a conventional intake tunnel. The coarse stone surface would create a local heterogeneous flow field immediately over the intake surface, as areas of relatively high velocity between stones would alternate with areas of minimal velocity directly over individual stones. The proposed stone size (20 to 30 cm diameter) was large enough that these "dead water" areas could be utilized for temporary refuge by fish encountering the intake flow. It was believed that the heterogeneous flow field plus the tactile cues presented by the stone surface would allow fish to perceive the intake and avoid entrainment in darkness as well as in daylight. In addition, the stone surface should provide visual orientation in daylight even under relatively turbid conditions.

The porous rock intake appeared technically feasible, but the potential existed for sediment fouling. Dr. A.E. Christie proposed a modified design, the porous rock veneer intake (Figure 2) to overcome potential siltation problems. In this design, a steel support structure would be constructed in a shallow excavation (3 to 4 m deep) around the vertical intake shaft. Then a thin veneer of coarse stone (approximately 1 m deep) would be added to form the porous rock barrier. As 20 to 30 cm diameter stones would be used, suspended sediment would

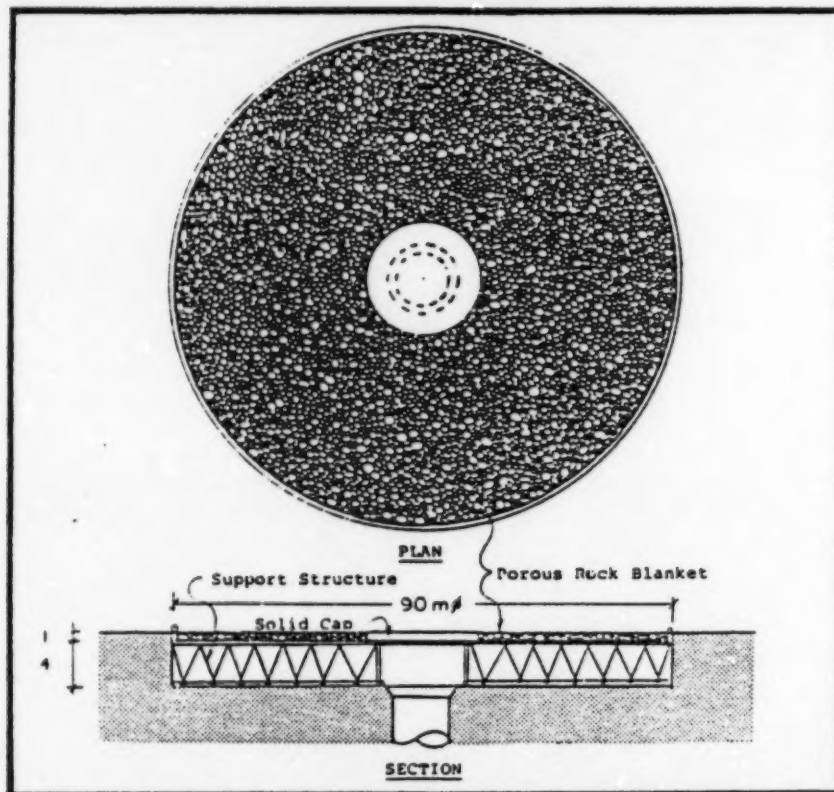


FIGURE 2
POROUS VENEER (ROCK BLANKET) INTAKE
(FROM CIVIL DESIGN REPORT 82434)

easily pass through the veneer openings. Moderately high velocities below the veneer surface would prevent any substantial silt accumulations in this area.

While the porous rock veneer appeared to circumvent potential siltation problems, desired porosity values could not be assured due to random variations in packing of the stones. Also, the stone surface could potentially be disturbed by wave action, even with a submergence of approximately 10 m in Lake Ontario. Therefore, construction of pre-cast surfaces (PPB type) was suggested. These surfaces would retain the essential characteristics of the stone veneer (relatively large openings and substantial refuge areas between openings) but would be constructed to a specific porosity (approximately 35%) and would be resistant to wave action. As shown in Figure 3, the proposed intake structure is composed of a large number of modules (each 5.5 m square) which would be constructed on shore and placed into the intake excavation. The intake configuration shown in Figure 3 has been developed from a number of conceptual engineering and hydraulic investigations (Design and Development Division Reports 82490 and 82434, Civil Design Department; Design and Development Division Report 82650, Hydraulic Studies and Development Department). Additional studies on hydraulic performance, potential for frazil ice fouling and stability under wave forces are presently ongoing.

2.0 APPARATUS AND PROCEDURES

2.1 Intake Test Facility

The intake test facility is based on a 15 m square concrete tank approximately 1.5 m deep. The six intake pumps (capacity $0.113 \text{ m}^3/\text{s}$ each) withdrew water from a central hexagonal intake basin and discharged at the north and south walls of the tank (Figure 4). The tank was back-filled with about 0.5 m of gravel to cover the intake piping. A concrete skin was poured over the gravel to provide a smooth, uniform bottom, flush with the intake basin. Water depth over the intake surface was approximately 1 m. A plywood roof was constructed on the intake basin. A 3.7 m square opening was made in the roof. This opening was covered by the intake test panels. A support frame was fabricated to allow either the entire 3.7 m square area to function as an intake, or alternately, a reduced intake surface 1.8 m square could be tested. The large (3.7 m square) intake was capable of producing velocities up to approximately 15 cm/s (mean design velocity for porous intake) while the small (1.8 m square) intake was capable of producing velocities approximately 60 cm/s (4X mean design velocity).

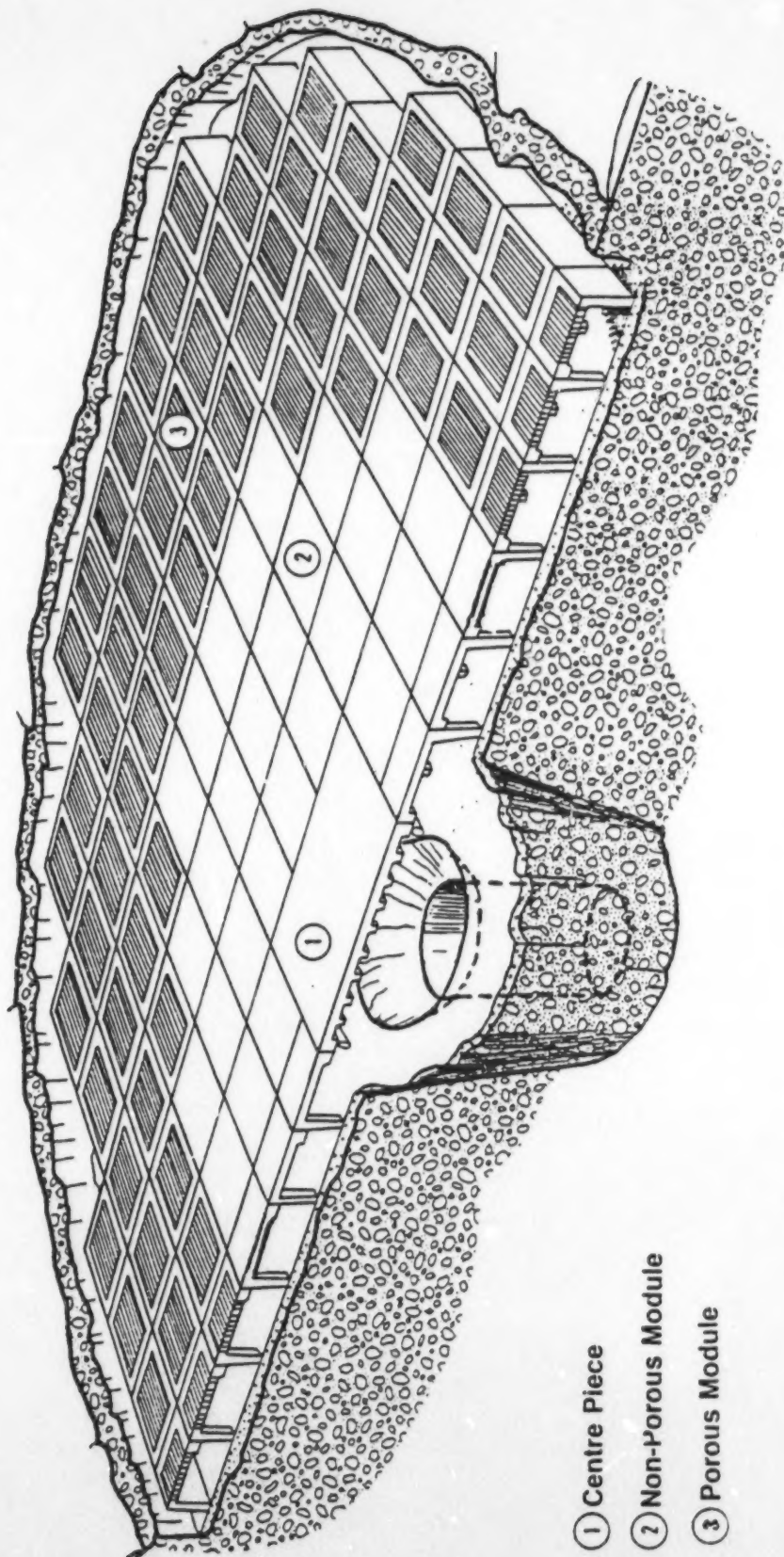


FIGURE 3
 PRECAST POROUS VENEER INTAKE - SECTIONAL VIEW
 (FROM CIVIL DESIGN REPORT 82434)

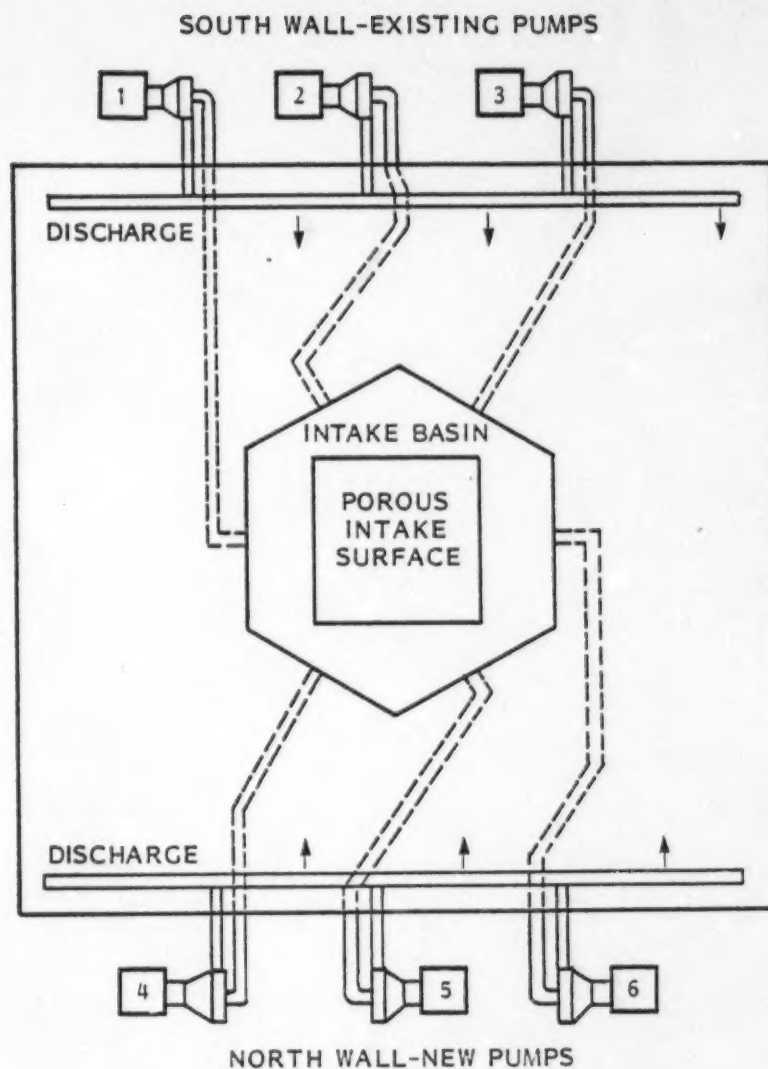


FIGURE 4
MODIFIED INTAKE MODEL - 1982
FISH DETERRENCE TESTS

The intake surfaces were designed to be reversible, providing an intake with projecting or flush intake ports (Figure 5). While fish avoided entrainment through all intake surfaces tested in 1981, greater avoidance of the immediate intake area was shown for those surfaces having projecting intake ports (lower percentage of fish observed actually passed over the intake ports).

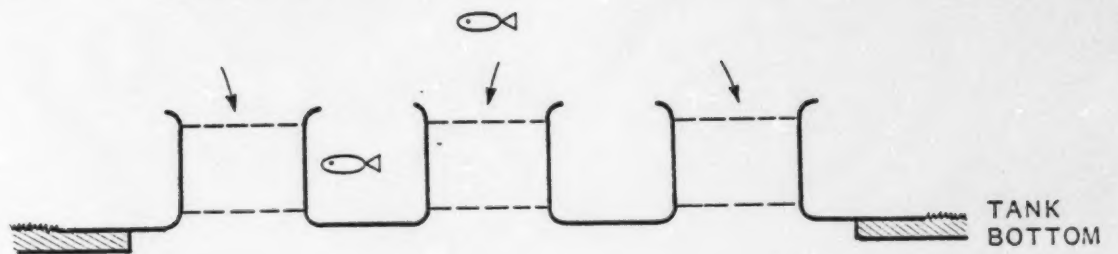
The intake ports in the 1982 intake surfaces were 14.5 cm wide slots arranged in rows on 30 cm centers. Vertical dividers (0.7 cm thick material) were placed on 14 cm centres. Porosity (for both large and small intake surfaces) was 34.9%. The dividers were added as it was felt that they would provide both visual and tactile cues which would reduce entrainment.

A wire mesh fence (approximately 10 m diameter) was constructed around the intake to contain the test fish. This was found necessary to ensure repeated encounters with the intake flow. The entire interior of the tank was painted with a non-toxic vinyl paint. A light green colour was used to simulate lake bottom conditions and allow test fish to be easily seen (Figure 6).

A low-light TV camera was mounted vertically above the intake to observe fish movements. A video tape recorder with a slow-motion playback allowed each encounter with the intake to be carefully monitored. The system was useful for daylight (approximately 10 lux) and most twilight (10^{-3} to 10^{-4} lux) tests, but could not be used in darkness.

A rope net barrier was fabricated for comparative tests. This consisted of a coarse square mesh constructed of heavy nylon rope. Vertical strands were 5 cm thick and horizontal strands were 2.5 cm thick, creating clear openings of 10 cm square. Porosity of this barrier was approximately 53%. The rope net was attached to a 2.74 m square frame (mounted at the center of the intake model) and extended from the bottom of the test tank to the water surface (Figure 7A). Water depth was 1 m. The rope net barrier was sized such that through-port velocities would be comparable (approximately 15 cm/s) to those of the 3.7 m square porous intake (35% porosity) when both systems were operated with all six intake pumps. However, it was noted by W.R. Jenkner (COTC Chairman) that due to the porosity factor for the rope net barrier, through-port velocities of this system (as installed on a Bruce GS 'B' type intake) would approximate 30 cm/s. To simulate this condition, the upper half of the rope net barrier was blocked off with plastic sheeting, approximately doubling the through-port velocity. In tests with alewife, limited fish availability allowed comparison of only the unrestricted (low velocity) rope net barrier with the porous

1. PROJECTING INTAKE PORTS



2. FLUSH INTAKE PORTS

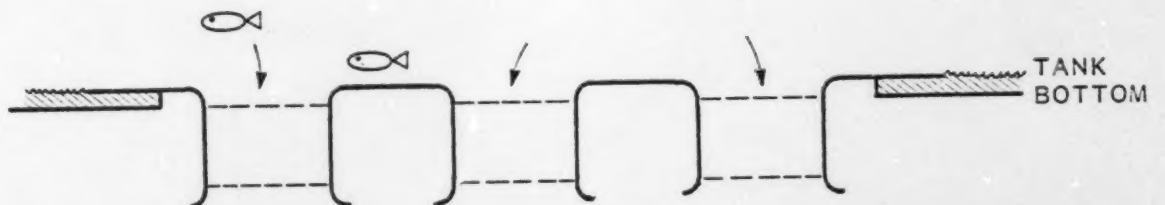


FIGURE 5
CONFIGURATIONS OF INTAKE TEST SURFACES

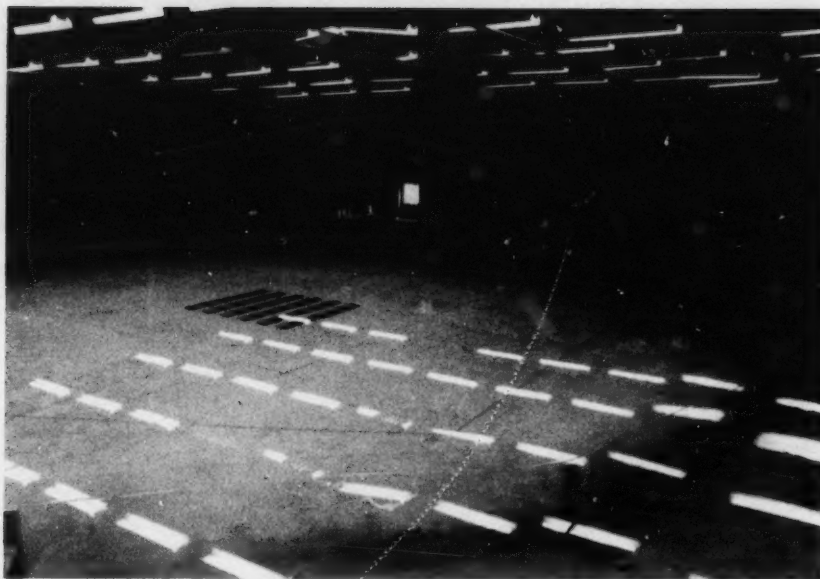
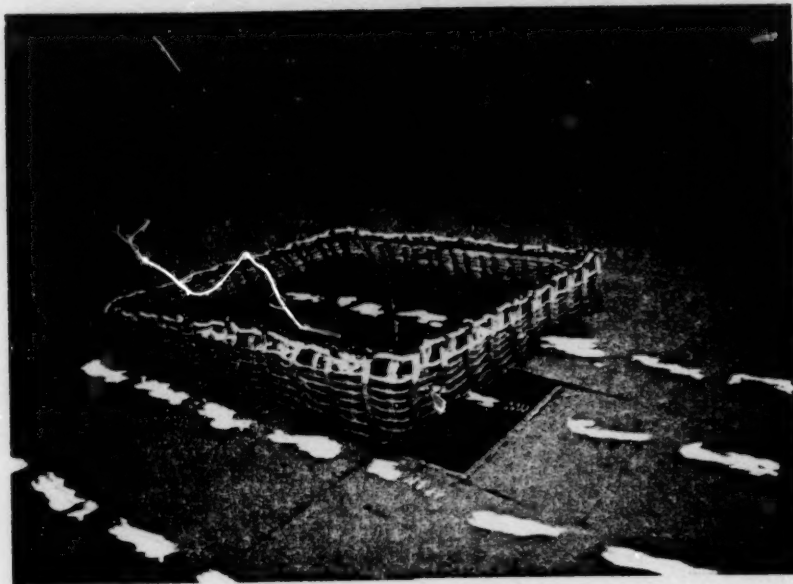


FIGURE 6

INTAKE TEST FACILITY

- 1.8 METER SQUARE INTAKE WITH FLUSH PORTS
- FENCE RETAINS TEST FISH
- WATER DEPTH IS 1 METER
- NORMAL "DAYLIGHT" ILLUMINATION USED
- ONLY 2 ROWS OF LIGHTS

A. Rope Net Barrier



B. Porous Veneer - Projecting Ports



FIGURE 7

VENEER AND ROPE BARRIER INTAKES USED FOR COMPARISON TESTS.
PANEL REMOVED AT PERIPHERY OF ROPE BARRIER INDICATES
DIFFERENCE IN SIZE OF THE TWO INTAKES
WATER DEPTH IS 1 METER

intake. In yellow perch and rainbow smelt tests, the porous intake was compared with both the unrestricted and restricted rope barriers. The large porous intake (with projecting ports) used for these comparative tests is shown in Figure 7B.

2.2 Experimental Fish

Fish used in this study were species common to the nearshore areas of the Great Lakes. Pelagic schooling species such as alewife, rainbow smelt and gizzard shad make up the bulk of fish captured by Ontario Hydro CCW intakes (Design and Development Report 81481). Alewife, the most commonly captured of these species, was chosen as the principal pelagic fish for study. However, as stocks were difficult to obtain in late December and January, rainbow smelt were also used for comparisons between the PPB intake and the rope net barriers. The yellow perch was selected as a representative benthic species which might occasionally reach depths expected for a PPB intake (typically 10 m).

Alewife used for the incremental velocity and fixed velocity tests conducted over the August to October period were collected from Lake Ontario near Pickering GS. The alewife used for the rope net/PPB comparisons in November and December were collected from the forebay and screenwells of Bruce GS 'A' on Lake Huron. Rainbow smelt used in these comparison tests were collected from the forebay of Nanticoke GS (Lake Erie) in early January. Yellow perch were collected from the Orangeville Reservoir during July-August and used for testing over the August-January period.

All test fish were held in 3.6 m diameter indoor tanks supplied with dechlorinated Toronto tap water. Ambient temperatures ranged from approximately 16° to 8°C and day-length approximated natural photoperiod. Fish were fed diets which included chopped earthworms (all species), oatmeal (alewife) and commercial trout feed re-ground to form a moist, soft pellet (all species). Some fish (winter alewife and smelt) were tested shortly after capture and were held in the laboratory for only brief periods.

2.3 Test Procedures

Three types of experiments were conducted in 1982. Incremental velocity tests used the small (1.8 m square) intake surfaces, while fixed velocity tests used the large (3.7 m square) intake surfaces. Comparative tests used the large intake surface (projecting port version) and the two rope net configurations previously described. Test procedures for these experiments are described in detail below.

2.3.1 Incremental Velocity Tests

These experiments were conducted under low-level daylight (approximately 10 lux) using the small (1.8 m) intake surfaces. The test was begun with a single intake pump operating (approximately 10 cm/s velocity through intake ports). Additional intake pumps were added at 45 min intervals. The experiment was terminated in 270 min (4.5 h) after all six pumps had operated for 45 min, or when all fish had been captured. Twenty-five fish were used in each test. Videotape records were monitored to determine behavior of fish encountering the intake. At each intake velocity a maximum of 20 encounters were monitored in detail (track diagrams constructed). Most encounters consisted of groups of fish. In the alewife experiments, the majority of the fish formed a single school. Encounters were grouped into those passing over the intake ports and those coming within the field of view. The camera field of view extended approximately 0.6 m north and south of the intake surface and 1.0 m east and west of the intake surface. Numbers of fish in each encounter were recorded as each school entered the field of view. These were compared with numbers leaving the field of view as a check against any observed capture by the intake.

Three intake conditions were tested. The control consisted of an open intake port (1.8 m square) without a veneer surface. A 1.8 m intake surface with flush ports and a 1.8 m surface with projecting ports were also tested. Three replicate tests were conducted for each intake type. Alewife and yellow perch were tested in separate experiments.

2.3.2 Fixed Velocity Tests

These experiments were conducted with the 3.7 m square intake surface. The control consisted of an unobstructed opening (the intake support frame was removed). Intake surfaces with flush ports or projecting ports were tested. In these experiments, all six intake pumps were operated, producing a nominal through-port velocity of 15 cm/s. Tests were conducted for 1 h periods under low-level daylight (approximately 10 lux), twilight (approximately 10^{-3} lux) and complete darkness. Videotape records of fish response were obtained for the daylight and twilight tests. For the dark tests, only initial numbers of test fish (usually 25) and numbers captured by the intake could be obtained. As with the incremental velocity tests, three replicates were run for each condition. Alewife and yellow perch were tested separately.

2.3.3 Comparison Tests - Porous Intake versus Rope Net Barrier

Procedures for comparisons of the porous veneer intake and the rope net barrier were similar to those described above for fixed velocity tests. Only one porous surface (projecting ports, 3.7 m square) was used in these experiments. Alewife were tested with the porous intake and the unobstructed (low velocity) rope barrier. Smelt and yellow perch were tested with both low velocity and high velocity rope barriers as well as the PPB intake.

Four replicates were run for each test condition. Control tests, using the unobstructed 3.7 m square opening, were also included. Each replicate consisted of daylight, twilight and dark tests (1 h duration each) with approximately 1/2 h between each test. As some fish (those not entrained) were re-used for the different light conditions of each replicate, the temporal sequence was reversed (ie, dark, twilight, daylight) in two replicates to minimize bias inherent in re-use of fish. These procedures were used to conserve fish (stocks were difficult to obtain during the November-January test period). Also, removal of fish which were not entrained was very time consuming, as it was necessary to use a beach seine to capture fish in the large test tank. Comparison of replicate test results did not indicate any particular trend with regard to the sequence of testing within replicates.

The rope net barrier was extremely bulky, heavy and difficult to move. Thus it was not possible to alternate between the rope barrier and the porous intake for each replicate (as originally planned). For alewife, all rope barrier tests were conducted first, followed by control and PPB tests. A similar sequence was used for perch and smelt tests. In order to minimize temporal changes in condition of fish stocks, six tests were conducted each day. Smelt and perch stocks remained quite healthy throughout the testing period. Alewife were available in only small numbers during the November-December test period and stocks obtained differed considerably in condition (from fair to extremely poor). Thus, differences in condition of alewife substantially complicates interpretation of the comparative test series for this species.

3.0 RESULTS

3.1 Incremental Velocity Tests

When the incremental velocity tests were planned, it was assumed that the majority of test fish would be captured over the range of velocities available (nominal through-port speeds from 10 cm/s to 60 cm/s). This proved to be the case for yellow

perch, but not for alewife. Consequently, it was possible to make a detailed analysis of velocity/capture relationships only for yellow perch. Measured velocities for all intakes used are listed in Appendix 1. Catch data for incremental velocity tests are listed in Appendix 2. All incremental velocity tests were conducted in daylight.

Fish exposed to incrementally increasing velocities in experimental water tunnels display a range of fatigue velocities similar to dosage-response relations in toxicity studies (Brett, 1965; Griffiths and Alderdice 1972; Griffiths, MS1978). Thus a plot of velocity (log scale) against cumulative percentage fatigued (probit scale) yields a relatively linear relationship. Yellow perch data from the present incremental velocity tests have been used to create a set of similar log-probit plots (Figure 8). Results indicate that the relationship between percentage capture and velocity is generally linear. Although substantial numbers of test fish were captured by the two intake surfaces at the highest test velocities, it is obvious that these surfaces substantially reduce capture compared with the open intake (Figure 8A). Both intake surfaces yielded similar capture rates (70% to 80%) at high velocities (50 to 60 cm/s), but the intake with flush ports appeared superior at lower velocities (10 to 30 cm/s). Over the range of velocities expected in the field for the porous intake (7 cm/s to 30 cm/s; 15 cm/s average) the intake with flush ports captured from 1% to 40% of the test fish. The intake with projecting ports captured from 10% to 50% of the perch.

In Figure 9, the log-probit plots from perch data are compared with results obtained from alewife. It is clear that the alewife were much more successful at avoiding capture. When the intake cap was not present, alewife captures increased from 1% to 44% over the 10 cm/s to 60 cm/s velocity range. With the flush port intake, alewife were not captured below 40 cm/s and only 10.8% were caught at the highest velocity. No alewife were captured by the intake surface with projecting ports.

The results in Figures 8 and 9 indicate the percentage of test fish captured at various speeds imposed for 45 min periods. However, these results do not consider the fact that during the test periods, individual fish (and groups of fish) may have repeatedly crossed the intake prior to capture. Videotape records were used to determine the numbers of fish crossing the intake ports or passing within the field of view of the camera (within 0.6 to 1 m of intake ports). Results for the incremental velocity tests (all speeds combined, total of three replicate tests) are summarized in Table 1.

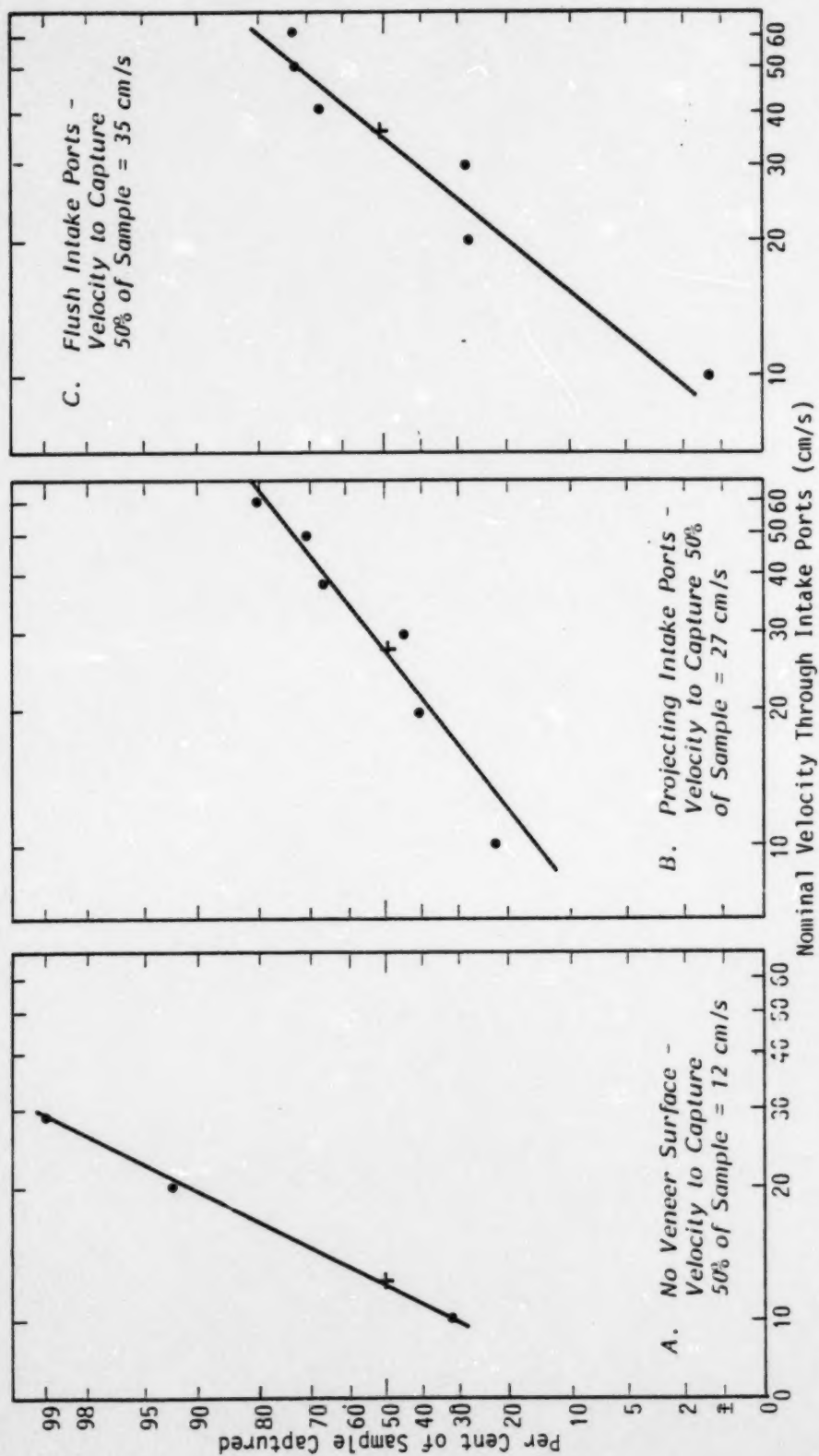


FIGURE 8
EFFECTS OF INTAKE VELOCITY AND SURFACE TYPE ON CAPTURE OF YELLOW PERCH
1.8 METER SQUARE INTAKE IN DAYLIGHT

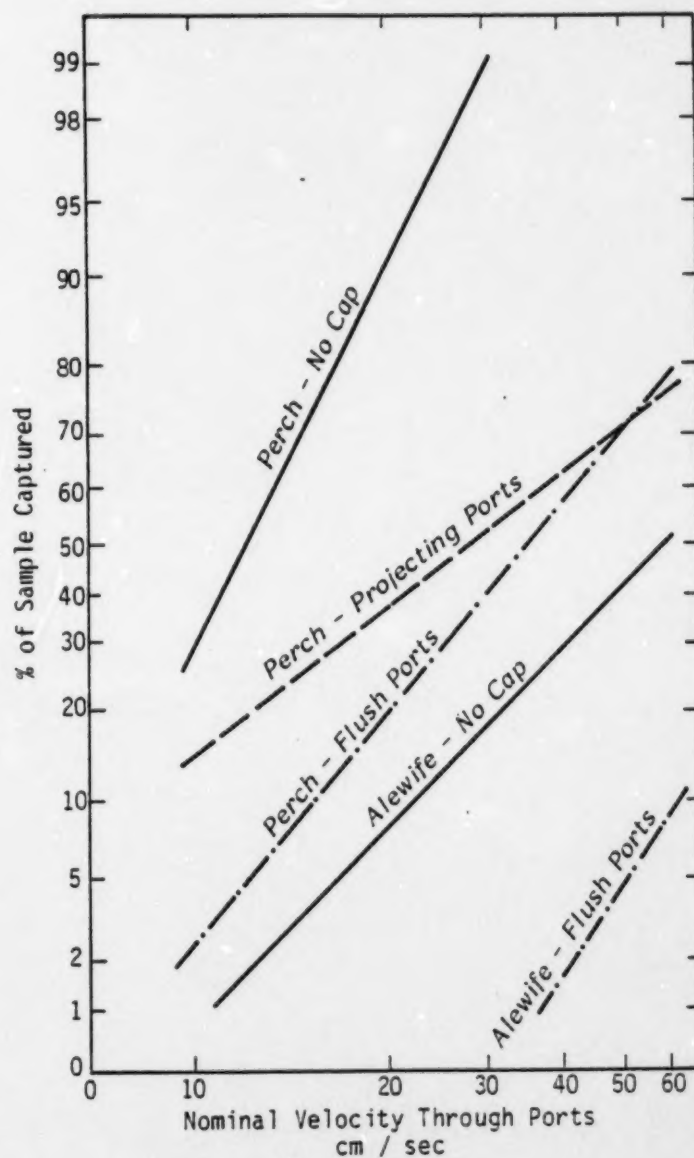


FIGURE 9
COMPARISON OF YELLOW PERCH AND
ALEWIFE RESULTS - INCREMENTAL VELOCITY TESTS

Results indicate that during the course of these tests, extremely large numbers of alewife passed within the vicinity of the operating intake, ie, within the field of view of the TV camera. Most fish observed were in discrete schools. Average group sizes for the three intake types tested ranged from 12 to 17 fish. Due to the large number of encounters, not all were examined in detail. Up to 20 encounters were monitored in detail at each velocity in a given replicate test. Thus, for the three replicates, up to 60 encounters were monitored in detail for each speed. The total alewife numbers observed are shown in parentheses in Table 1, other numbers (over ports, within field of view) refer to the fish monitored in detail. As yellow perch encounter frequency was much lower, all perch encounters were monitored in detail.

The data in Table 1 suggest differences in behavioral response of alewife to the intake configurations tested. Of the fish monitored in detail, only approximately 20% of alewife entering the field of view crossed the open intake port (no cap) suggesting that the open 1.8 m intake was readily perceived by the fish and actively avoided. In contrast, 60% of the alewife entering the field of view crossed the intake surface with flush ports, while 40% crossed the surface with projecting ports. Of those alewife passing over the intake ports, 5.8% were captured by the open intake, 0.28% were captured by the intake with flush ports and none were captured by the intake with projecting ports.

Thus, it appears that while alewife actively avoided passing over the open intake, those fish that did pass over the 1.8 m opening were more vulnerable to capture than fish passing over the porous surfaces. The intake surface with flush ports was probably less visible at a distance, and strong avoidance did not usually occur until the fish were very near or over the intake ports. However, the percentage of fish captured was very low, and as previously noted, no captures occurred at velocities below 40 cm/s. The intake with projecting ports appeared to give the best results with alewife, as greater avoidance was shown at some distance from the intake (lower percentage of fish passing over ports compared with flush intake) and no fish were captured at any velocity.

Yellow perch results differed substantially from those obtained with alewife (Table 1). Perch showed little avoidance of the open intake, as 95% of the fish entering the camera field of view passed over the open 1.8 m port. Some avoidance of the flush and projecting port intakes was shown, as the percentages of fish passing over the ports were 65% and 54%, respectively. However, the general activity level of perch was much lower than alewife, and avoidance of capture was very poor. Over the total range of velocities tested, 96% of the perch passing over the

TABLE 1
1982 POROUS INTAKE STUDIES - DATA SUMMARY FOR
INCREMENTAL VELOCITY TESTS (ALL VELOCITIES COMBINED)

Test Conditions	Fish Observed			Fish Captured			
	Over Intake Ports	Within Field of View	% Over Intake Ports	Total Number	% Of Total Observed	% of Fish Over Ports	% of Sample
Alewife - No Cap	572	2927 (4209)	19.5	33	0.8	5.8	44.0
Alewife - Flush Ports	2890	4814 (7581)	60.0	8	0.1	0.17	10.7
Alewife - Projecting Ports	1862	4646 (7984)	40.0	0	0	0	0
Perch - No Cap	78	82	95.1	75	91.5	96.1	100
Perch - Flush Ports	133	203	65.5	55	27.1	41.4	73.3
Perch - Projecting Ports	153	281	54.4	62	22.1	40.5	82.7

open 1.8 m intake were captured. The two intake surfaces yielded similar captures (41.4 and 40.5%). As noted previously, capture of yellow perch was directly related to intake velocity and was somewhat below these values for the mean velocity expected in a porous veneer field installation. Fortunately, at most Great Lakes sites, pelagic species (alewife, smelt, shad) are likely to account for more than 90% of the fish present at typical 10 m intake depths.

3.2 Fixed Velocity Tests

Fixed velocity tests were run at approximately 15 cm/s (through-port velocity) using the large 3.7 m square intake surfaces for 1 h periods in daylight, twilight and darkness. Alewife and perch results are summarized in Table 2. Results for individual replicates (3 runs) are listed in Appendix 3.

Alewife capture data (Table 2) indicates that capture rates for the large intake were considerably greater than those obtained with the small (1.8 m) intake, despite the lower velocities used with the large intake surfaces. Presumably, this is the result of greater area (4X that the small surface) and the corresponding reduction of the refuge area surrounding the intake surface, reducing the opportunities for escape.

Alewife control captures (Table 2) were reasonably consistent (67 to 70%) at all light levels. Results for the porous surface with flush ports suggest an increased capture in dark tests. However the data are quite variable (means $\pm$ Standard Deviation shown). Both flush and projecting port intake surfaces substantially reduced capture compared with the open intake control. Reductions ranged from 59.7% to 89.8%. Mean percentage reductions (all light conditions) for the flush port and projecting port intakes were 75% and 78%, respectively.

Encounter data indicates that in daylight and twilight, 69% and 86%, respectively, of the alewife coming within the camera field of view (approximately 2 m on each side of the intake) actually passed over the open intake port. Thus, the strong avoidance of the control intake shown by alewife in the incremental velocity tests was not evident. This difference in behavior may be due to the lower current velocities of the large intake opening, or it may reflect differences in stocks of fish used in these tests. Incremental velocity tests were conducted in August-September, using alewife which appeared to be in good physical condition. Alewife used in the fixed velocity tests were tested in late October and were in quite poor condition. From the data in Table 2, only the projecting port intake (tested in daylight) appeared to be substantially avoided by alewife, as only 53% of the observed fish crossed this intake surface.

TABLE 2
FIXED VELOCITY TESTS - LARGE POROUS INTAKE

Treatment	Capture Data		Encounter Data			
	% of Sample Captured	% Reduction From Control	% of Fish Crossing	% of Encounters Captured	% of Crossing Fish Captured	% Reduction* From Control
Alewife-Day-Control	66.7±33.5		69.0	11.09	16.08	
Alewife-Twilight-Control	70.4±11.8		86.1	22.22	25.81	
Alewife-Dark-Control	70.0±12.5					
Alewife-Day-Flush	16.3±4.4	75.6	64.6	1.13	1.75	89.12 (89.81)
Alewife-Twilight-Flush	7.2±6.3	89.8	67.8	0.38	0.56	97.83 (98.29)
Alewife-Dark-Flush	28.2±23.0	59.7				
Alewife-Day-Projecting	20.0±14.4	70.0	53.4	2.90	5.43	66.23 (73.85)
Alewife-Twilight-Projecting	12.3±12.5	82.5	65.4	1.96	3.00	88.38 (91.18)
Alewife-Dark-Projecting	12.7±16.8	81.9				
Perch-Day-Control	77.3±39.3		98.3	98.30	100.00	
Perch-Twilight-Control	49.3±10.1		73.1	57.69	78.94	
Perch-Dark-Control	39.1±7.8					
Perch-Day-Flush	42.7±50.0	44.8	76.2	76.19	100.00	0.00 (22.49)
Perch-Twilight-Flush	30.7±28.4	37.7	91.3	60.87	66.67	15.54 (-5.51)
Perch-Dark-Flush	57.5±6.6	-47.1				
Perch-Day-Projecting	33.3±51.0	56.9	88.1	59.50	67.57	32.43 (39.47)
Perch-Twilight-Projecting	24.9±18.1	49.5	76.2	42.86	56.25	28.74 (25.71)
Perch-Dark-Projecting	37.4±9.3	4.3				

* refers to captured/crossing data; captured/encounter data in parentheses

As in the incremental velocity tests, alewife captures were the result of many encounters with the intake flow. Of those fish crossing the open (control) intake, capture rates were 16% in daylight and 26% in twilight. Much lower capture rates were observed for the two porous surfaces, with mean values being slightly lower in twilight tests. Compared with control capture rates (of fish crossing the intake), results for the two intake surfaces suggest reductions ranging from 66% to 98%. The flush port intake yielded the highest mean reduction (93% compared with 77% for the projecting port intake). However, as previously noted, alewife captures were relatively high (28%) with this intake surface in darkness.

Perch control catches were highest (77%) in daylight, declining to 39% in darkness (Table 2). These results are consistent with expected perch behavior, as perch become quite inactive and often rest on the bottom in darkness.

Lowest percentage capture occurred in twilight tests and highest capture occurred in dark tests for both intake surfaces. Compared with control catches, the intake surfaces substantially reduced capture (38% to 57%) in both daylight and twilight tests, but were ineffective in darkness. Encounter data indicates that the perch did not avoid crossing the intake, as from 76% to 98% of fish entering the field of view crossed the intake ports. Perch which crossed the intakes were very vulnerable to capture. This was especially true for the open control intake, which caught 100% of the crossing perch in daylight and 79% in twilight. The lowest capture rates (68% in daylight, 56% in twilight) were obtained with the projecting port intake. However, these values represent a reduction of only about 30% from control catches.

3.3 Comparisons of Porous Intake and Rope Net Barriers

3.3.1 Alewife

During the November-December 1982 test period, alewife stocks were extremely difficult to obtain. Condition of the fish, while generally poor, was quite variable. A group of fish was obtained from the forebay of Bruce GS 'A'. They were used for tests of the low velocity rope net barrier (Rope 1), followed by a series of control tests. These fish were in fair condition, that is, their condition appeared to be better than that of alewife used in the October porous intake tests, but was not as good as the condition of alewife used in the August-September incremental velocity tests. Attempts were made to obtain additional alewife for the porous intake tests in mid-December but few fish remained in the Bruce GS 'A' forebay. Alewife collected (from the screenwells) were in extremely poor condition.

As no other alewife were available, these fish were used for additional tests with the PPB intake. These results are included for comparison with the rope barrier tests. However, due to the extremely poor condition of the December PPB fish, results from the October tests have also been considered.

As in the previous fixed velocity tests, effectiveness of the intake types may be assessed by consideration of the gross percentage of test fish caught (daylight, twilight, dark tests) and the percentage of encounters resulting in capture (daylight, twilight tests only). The gross percentage capture data are summarized in Table 3 and listed in detail in Appendix 4. In Table 3, Veneer₁ refers to the December alewife tests with the projecting port surface, Veneer₂ refers to October tests with this surface, and Veneer₃ refers to October tests with the flush port surface.

Comparison of the open intake control results clearly indicates the difference in condition of the stocks used. The mean capture percentages for Control₁ (the group of fish used in the rope barrier tests) ranged from 41% in daylight to 55.6% in darkness, while the values for Control_{2/3} (the October fish tested with Veneer₂ and Veneer₃) ranged from 66.7% in daylight to 70% in darkness.

Analysis of Variance was used to test for differences between test treatments. As the data were in the form of percentages, the Arcsin transformation was used prior to analysis to increase the normality of error distribution (Snedecor and Cochran, 1967). Results indicate that in daylight tests (Table 3) there was no significant difference in capture percentages, despite a wide range in mean values (from 4.2% for the rope barrier to 66.7% for Control_{2/3}).

Twilight tests yielded significant differences in percentage capture (Table 3). In the October tests, both the flush port (Veneer₃) and projecting port (Veneer₂) intakes caught significantly fewer fish than their control (Control_{2/3}). In contrast, the capture percentage for the rope barrier was not significantly better than its control (Control₁). While this is suggestive of better performance by the porous surfaces, direct comparison of the PPB and rope barrier catches does not yield a significant difference. However, it should be noted that differences in alewife condition between experimental groups makes direct comparison rather suspect.

TABLE 3

ALEWIFE
ROPE NET/POROUS VENEER COMPARISON - PER CENT OF SAMPLE CAPTURED

Daylight	Rope ₁ n=4	Veneer ₃ n=3	Veneer ₂ n=3	Veneer ₁ n=4	Control ₁ n=4	Control _{2/3} n=3
$\bar{X} = 28.91$ ANOVA: $F = 2.39$ NS	4.1±5.7	16.3±4.4	20.0±14.4	29.5±21.1	41.0±39.5	66.7±33.5
Twilight	Veneer ₃	Veneer ₂	Rope ₁	Control ₁	Veneer ₁	Control _{2/3}
$\bar{X} = 37.21 \pm 25.37$ ANOVA: $F = 8.25^{**}$	7.2±6.3	12.3±12.5	28.8±3.9	44.0±17.3	55.1±23.4	70.4±11.8
Multiple Range Test:	-----					
Darkness	Veneer ₂	Veneer ₃	Control ₁	Veneer ₁	Rope ₁	Control _{2/3}
$\bar{X} = 45.44 \pm 26.25$ ANOVA: $F = 3.13^*$	12.7±16.8	28.1±22.9	46.0±20.8	53.8±29.1	55.6±21.6	70.0±12.5
Multiple Range Test:	-----					

In dark tests, Veneer₂ (projecting ports, October test) captured significantly fewer fish than its control (Table 3). While the rope barrier actually captured more fish than its control (Control₁) this difference was not significant. All three PPB test series yielded lower mean catches than the rope barrier in darkness, but these differences were not significant.

Videotape records provided data on the percentage capture of individual encounters with the intakes during daylight and twilight tests. Videotape records for the October tests (Veneer₂ and Veneer₃) were incomplete, as twilight light levels were occasionally insufficient to produce a useable tape. Thus, only the data gathered from December tests have been used for comparison with the rope net results. Results summarized in Table 4 indicate that the percentages of encounters resulting in capture were considerably lower than gross capture values, ie, repeated encounters with the intake flow were required to generate the capture percentages in Table 3. A two-way Analysis of Variance was used to analyze the encounter data in Table 4. Although the average percentage of encounters captured with the porous intake was less than half that of the rope barrier, this difference was not significant. The large between-replicate variability of the daylight rope barrier data (SD twice the mean) probably contributes to these results. When the data were analyzed by separate one-way ANOVAs, daylight results did not differ significantly. In twilight tests, the percentages of encounters resulting in capture for control and PPB tests were significantly lower than values obtained for the rope barrier.

3.3.2 Rainbow Smelt

Smelt stocks remained quite healthy through the January 1983 test period. Thus there was no obvious between-treatment bias due to differing stocks of fish (as was evident for alewife). Results are listed in detail in Appendix 4. Percentage capture data summarized in Table 5 indicate that the high velocity rope net barrier (Rope 2) caught significantly more smelt than the open control intake. Differences in mean capture percentages of other intake types were not significant. Capture percentage increased significantly (approximately doubled) between daylight and darkness, while twilight captures were only slightly higher than those in daylight.

TABLE 4
ALEWIFE
ROPE NET/POROUS VENEER COMPARISON -
PER CENT OF ENCOUNTERS CAPTURED

Light Condition	Veneer ₁	Control ₁	Rope ₁
Daylight $\bar{X} = 4.98 \pm 7.80$	1.94 $\pm$ 1.49	6.62 $\pm$ 6.96	6.38 $\pm$ 12.42
Twilight $\bar{X} = 5.68 \pm 2.96$	4.47 $\pm$ 2.07	3.61 $\pm$ 1.55	8.96 $\pm$ 1.84
Mean:	3.20 $\pm$ 2.15	5.12 $\pm$ 4.94	7.67 $\pm$ 8.33
ANOVA (2-way): Intakes: F=0.45 NS Light: F=1.70 NS	(n=8)	(n=8)	(n=8)

Twilight: (1-way ANOVA):
F=7.46*

Multiple Range	Control ₁	Veneer ₁	Rope ₁
Test:	3.61 $\pm$ 1.55	4.47 $\pm$ 2.07	8.96 $\pm$ 1.84

The encounter data summarized in Table 6 indicate that in daylight and twilight tests, the percentage of smelt encounters captured by the porous intake was approximately 1/2 to 1/3 of the values obtained from the low velocity and high velocity rope net barriers, respectively. However, these differences were not statistically significant due to the high between-replicate variability of the rope net data. Across all intake types tested, there was a significant increase in encounters captured from daylight to twilight. The increase was approximately three-fold on average, but the control increase was only minor (Table 6).

3.3.3 Yellow Perch

Yellow perch stocks remained healthy and showed no obvious sign of change in condition over the October to December test period. However, considerable between-replicate variability was

TABLE 5

RAINBOW SMELT
ROPE NET/POROUS VENEER COMPARISON - PER CENT OF SAMPLE CAPTURED

Light Condition	Control	Veneer	Rope ₁	Rope ₂
Daylight $\bar{X} = 35.9 \pm 17.9$	27.2 $\pm$ 24.1	35.0 $\pm$ 8.9	42.2 $\pm$ 10.4	39.0 $\pm$ 25.6
Twilight $\bar{X} = 37.9 \pm 16.3$	29.6 $\pm$ 27.8 (n=4)	34.0 $\pm$ 9.5 (n=4)	39.7 $\pm$ 11.8 (n=7)	48.2 $\pm$ 7.7 (n=7)
Darkness $\bar{X} = 64.8 \pm 23.8$	42.0 $\pm$ 29.3	59.3 $\pm$ 19.9	74.0 $\pm$ 10.1	83.9 $\pm$ 11.6
Means: ANOVA (Two-way) Intakes: F=4.40** Light: F=12.03**	32.9 $\pm$ 25.5 (n=12)	42.8 $\pm$ 17.4 (n=12)	52.0 $\pm$ 19.0 (n=12)	57.0 $\pm$ 25.3 (n=12)
Multiple Range Test: Intakes:	-----			

MULTIPLE RANGE
TEST (Light)

Daylight
35.9

Twilight
37.9

Darkness
64.8

evident in all tests, especially those conducted in daylight. In order to obtain the best estimate of response (with existing data) the October PPB (projecting port) and control samples were combined with those obtained in December, increasing sample sizes to seven replicates for these treatments (Table 7). Mean capture percentages for the porous intake and the low velocity rope net (Rope₁) in daylight were considerably lower than those for the high velocity rope net (Rope₂) and the open intake control. However, as both the PPB and low velocity rope barrier results were extremely variable, differences were not statistically significant.

TABLE 6

RAINBOW SMELT
ROPE NET/POROUS VENEER COMPARISON - PER CENT OF ENCOUNTERS CAPTURED

Light Condition	Veneer	Control	Rope ₂	Rope ₁
Daylight $\bar{X} = 4.78 \pm 5.30$	2.81 ± 1.59	7.16 ± 1.75	2.17 ± 1.54	6.99 ± 10.20
Twilight $\bar{X} = 15.68 \pm 15.40$	7.49 ± 4.95	8.75 ± 8.52	23.66 ± 12.69	22.84 ± 24.91
Mean:	5.15 ± 4.22	7.95 ± 5.76	12.91 ± 5.76	14.92 ± 19.55
ANOVA (2-way): Intakes: $F=1.17$ NS Light: $F=10.89^{**}$	(n=8)	(n=8)	(n=8)	(n=8)

In twilight tests, the percentage capture for the low velocity rope net was significantly lower than that for the high velocity rope net (Table 7). Porous intake and control captures were intermediate between these two extremes and were not significantly different from either set of rope net values.

Perch catches in dark tests with the high velocity rope net barrier were significantly higher than control catches (Table 7). Catches by the low velocity rope barrier and the porous intake were slightly higher than the control and were not significantly different from either the control or high velocity rope barrier catches.

TABLE 7

YELLOW PERCH
ROPE NET/POROUS VENEER COMPARISON - PER CENT OF SAMPLE CAPTURED

Daylight	Veneer	Rope ₁	Rope ₂	Control
$\bar{X} = 67.23 \pm 39.01$ ANOVA: F = 1.44 NS	49.7 ± 44.8 (n=7)	51.0 ± 56.6 (n=4)	83.3 ± 7.7 (n=4)	84.8 ± 25.0 (n=7)
Twilight	Rope ₁	Veneer	Control	Rope ₂
$\bar{X} = 48.52 \pm 23.60$ ANOVA: F = 4.31*	23.5 ± 10.9 (n=4)	41.5 ± 26.6 (n=7)	58.3 ± 17.3 (n=7)	68.6 ± 7.9 (n=4)
Multiple Range Test:	-----			
Darkness	Control	Rope ₁	Veneer	Rope ₂
$\bar{X} = 48.68 \pm 15.62$ ANOVA: F = 3.49*	41.9 ± 10.9 (n=7)	43.0 ± 15.4 (n=4)	48.0 ± 12.4 (n=7)	67.3 ± 17.6 (n=4)
Multiple Range Test:	-----			

ANOVA (Light Conditions):
F = 3.51*

MULTIPLE RANGE
TEST:

TWILIGHT
(n=22)
48.52

DARKNESS
(n=22)
48.68

DAYLIGHT
(n=22)
67.23

The perch catch data (all treatments) indicates a general significant decrease in catch from a 67% average in daylight to 49% in darkness. The decrease in catch was most notable for the open control intake. Control catches declined from 84.8% in daylight to 41.9% in darkness ($p < 0.01$).

Encounter results for yellow perch are summarized in Table 8. As some twilight videotapes from the October tests were of poor quality, only the December test results (four replicates/treatment) were used for this comparison. While the percentage of encounters captured was lowest for the high velocity rope barrier and highest for the control intake, between-replicate variability was too great for the differences to be declared significant. Both the two-way ANOVA in Table 8 and separate one-way ANOVAs for daylight and twilight were conducted without significance being obtained. However, as indicated in Table 8, there was a significant decrease in the percentage of encounters captured between daylight and twilight tests.

TABLE 8

YELLOW PERCH
ROPE NET/POROUS VENEER COMPARISON - PER CENT OF ENCOUNTERS CAPTURED

Light Condition	Rope ₂	Veneer	Rope ₁	Control
Daylight $\bar{X} = 37.47 \pm 34.22$	10.17 $\pm$ 6.24	29.27 $\pm$ 31.99	47.41 $\pm$ 48.53	63.02 $\pm$ 33.69
Twilight $\bar{X} = 11.58 \pm 16.11$	4.86 $\pm$ 1.51	8.27 $\pm$ 6.18	11.01 $\pm$ 10.17	22.17 $\pm$ 30.49
Mean:	7.52 $\pm$ 5.07	16.77 $\pm$ 24.11	29.21 $\pm$ 33.10	42.59 $\pm$ 36.90
ANOVA (2-way): Intakes: $F = 2.74$ NS Light: $F = 8.11$ **	(n=8)	(n=8)	(n=8)	(n=8)

4.0 DISCUSSION

4.1 Behavior of Test Species in the Laboratory Tank

In general, the two pelagic species (smelt and alewife) behaved similarly, and quite differently from the benthic species (yellow perch) used in these experiments. However, some differences in response were apparent for the pelagic species. Total catches of both alewife and smelt increased with decreasing

light levels (from daylight to darkness). While smelt capture/encounter data showed a significant increase from daylight to twilight, the percentage of alewife encounters captured did not increase significantly. Also, alewife activity (total number of encounters in all tests) was quite consistent between daylight (2683) and twilight (2739). Smelt activity declined from 5479 encounters in daylight to 1543 encounters in twilight. Thus, the results suggest that while smelt activity decreased in low light levels, the susceptibility to capture of individuals encountering the intake actually increased. As smelt are generally considered to be more nocturnal than alewife and are assumed (at least by this author) to have better visual acuity in dim light, these results were quite unexpected. Also, while present results were obtained from alewife stocks in rather poor condition, the smelt appeared to be in reasonably good condition. With regard to capture percentages in complete darkness, (compared for veneer, rope, and control) the smelt capture (58.4%) was somewhat higher than that for alewife (44.4%). It is not clear whether these values reflect differences in activity (active fish would encounter the intake more frequently) or whether there are differences in susceptibility to capture once an encounter has occurred.

The poor capture avoidance shown by yellow perch in the large porous veneer and rope barrier tests is consistent with the results from this species in the incremental velocity tests. Capture of perch by these intakes does not appear to be the result of intake velocities exceeding the swimming capacity of the species (at velocities <30 cm/s), as videotape records did not show any instances of perch being entrained tail-first. Instead, captured fish simply swam over the intake and were drawn through the ports without taking avoidance action, or more commonly, swam head-first into the intake ports. It should be noted that in the absence of intake currents, perch would deliberately swim into the intakes (especially the open control intake) apparently choosing the intake as a refuge. A greater degree of avoidance was apparent when the intakes were operating, but clearly the avoidance response was not very strong.

Unlike smelt and alewife, perch results showed a significant decline in both total catch and catch/encounter as light levels decreased. However, the total number of encounters in twilight (3297) was substantially greater than in daylight (1955). Thus, the decrease in total catch cannot be attributed to decreased activity in dim light. Instead, it appears that in twilight, the perch were less prone to seek refuge in the "cover" provided by the intake structures. The behavior of perch in this experimental system is apparently complex. While they appear to be attracted to the intake structures as a potential refuge, entry

into the intake may be deterred by the rapidly accelerating currents near the intake openings. If this hypothesis is correct, it would explain why the high velocity rope net produced the lowest catch/encounter percentage, while the open control intake (with the lowest through-port velocity) produced the highest catch/encounter percentage.

The behavior exhibited by perch in these tests may be an artifact created by the experimental system, as the test tank was generally smooth and featureless. Only the perimeter fence and the intake structures offered the perch any opportunities for refuge. The shallowness of the test tank (1 m) probably also contributed to the tendency of these fish to seek areas of cover. Presumably, a porous intake installed in the field would be less attractive as a refuge area for yellow perch, as natural refuge areas would likely be available.

4.2 Comparison of Porous Intake and Rope Net Barrier

Studies conducted in this laboratory have indicated that a coarse rope net barrier should be an effective means of reducing capture of pelagic fish (alewife, smelt, gizzard shad) by condenser cooling water intakes (Ontario Hydro Research Division Report No 81-190-K). Field trials of this barrier (10 m long sections) at the mouth of the Pickering GS intake indicated a substantial reduction (79%) in alewife catch when the barrier was in place (Ontario Hydro Research Division Report in preparation). Although the laboratory tests indicated that barrier effectiveness would be enhanced with illumination by strobe lights, reliability problems were encountered with strobe lights in the field. Also, the results suggested that far-field attraction to unsynchronized multiple strobe lights (which produced a nearly constant light source) was a problem. However, the field results also indicated that for alewife, effectiveness of an unilluminated barrier was very high (86% reduction compared with control). Barrier effectiveness in darkness was actually higher than in daylight (63% reduction).

While the available data thus indicate that the rope net barrier would be an effective fish deterrent, direct comparison with the porous intake results obtained up to October 1982 in the present study was not possible due to differing test methodologies. The laboratory rope net barrier was tested in circular and oval tanks (Ontario Hydro Research Division Report No 81-190-K), using the reduction in number of fish passages past a specific point (compared with no-barrier controls) as a measure of effectiveness. In most cases, the actual numbers of fish passing through the rope barrier exceeded the total number of fish in a test, that is each fish was "captured" several times. Control passages (when the barrier was absent) were much higher

as there were no structures or features which the fish could use as a cue to determine that they were being entrained through an "intake". In this respect, the controls were probably representative of fish being entrained (in mid-water) through a large velocity cap intake.

Present porous intake tests provided quantitative data on the actual numbers of fish captured by the intake as well as the avoidance success of fish coming within the immediate vicinity of the intake. However, the control intake in the present study (1.8 m or 3.7 m openings) clearly provided visual and/or current cues to fish being entrained and substantial avoidance of test fish was evident (although captures were higher than for the porous test intakes). Thus, direct comparison of experimental versus control captures for the present study and the previous laboratory rope barrier study was not possible. Comparative studies of the PPB and rope barrier were therefore added to the present investigation. The intention was to allow direct comparison of the porous intake and the rope net barrier using common apparatus, methodology and fish stocks.

Results obtained from these comparative tests indicate that the porous intake surfaces are at least as effective as the rope net barrier in reducing fish capture. Due to the high between-replicate variability and the limited number of test replicates which could be conducted in the available time, a statistically significant difference was found in only one test series (lower capture/encounter percentage for PPB in alewife twilight tests, Table 4). However, there was a general trend favouring the porous intake. Considering daylight, twilight and dark gross capture results, plus daylight and twilight capture/encounter results, there were 15 different data sets which could be used for rope net/PPB comparisons (each data set had from three to seven replicates). In nine of these data sets, the mean porous intake catch was lower than that of either (high or low velocity) rope barrier. Of the remaining six data sets, one of the rope barrier capture percentages (but not both) was lower than the PPB value. However, it should be realized that the velocity through a rope barrier installed on a conventional velocity cap intake would be equivalent to the value (≈ 30 cm/s) used in the high velocity rope net tests. The velocity of a PPB intake in a field installation would (on average) be equivalent to the laboratory tested value (≈ 15 cm/s) or less as the laboratory value includes a 25% fouling margin. Thus, comparison of the laboratory PPB and the high velocity rope barrier results would be most applicable to the field situation. In this case, there are 10 data sets available for comparison. The porous intake caught lower percentages of fish in seven of these tests.

Mean catch percentages generally favour the porous intakes. With alewife (combined daylight, twilight and dark tests) the PPB intakes captured 26.1% of the fish tested. If the December tests (using very poor fish) are excluded, the capture rate drops to 16.1%. In comparison, the low velocity rope barrier captured 29.5% of alewife tested. The high velocity rope barrier was not tested with this species. In smelt tests, the porous intake caught 42.8%, the low velocity rope net caught 52.0% and the high velocity rope net caught 57.0% of test fish. The PPB intake captured 46.4% of perch tested (combined October and December tests) while the low velocity rope barrier caught 39.2% and the high velocity rope barrier caught 73.1% of the perch.

The encounter data (daylight and twilight tests) also generally favour the porous intake. Only 3.2% of alewife encounters with the PPB resulted in capture, compared with 7.7% for the low velocity rope net. In smelt tests, 5.2% of encounters were captured by the porous intake, while the low velocity rope net captured 14.9% and the high velocity rope net captured 12.9% of the fish encountering this intake. Perch results, like the total catch data, were less clear-cut. The porous intake captured 18.8% of perch encounters and the low velocity rope net captured 29.2%, but the high velocity rope net captured only 7.5%.

The large between-replicate variability generally precludes PPB/rope barrier differences from being statistically significant. However, the general trends of both the total catch and encounter data suggest that the porous intake should provide better protection (especially for pelagic species) than a rope net barrier. Certainly, a conservative assumption would be that the porous intake would be at least as good as the rope barrier in reducing fish capture.

Extrapolation of laboratory test results to the field situation is at best a rather perilous procedure. However, it should be noted that for alewife, observed reductions in capture (control versus experimental) at the Pickering test barrier were quite similar to those obtained in earlier laboratory experiments (>70% reduction) despite rather different methods of assessment (Ontario Hydro Research Division Report No 81-190-K). In the present rope barrier tests with alewife, the reduction in catch relative to the control was only 32%. However, as previously discussed, the control intake used in present studies was actively avoided by pelagic species (smelt, alewife).

The most obvious difference between laboratory results (past and present) and the Pickering GS field trials of the rope net barrier has been the much better than expected performance of

the Pickering barrier in darkness. Light levels in all dark tests (laboratory and field) have been extremely low (not measurable with existing equipment). Hence, it is unlikely that avoidance during darkness is based on visual cues. It would seem more likely that fish in the field were able to sense the rope net barrier because of the noise or vibration caused by the intake currents flowing past the barrier and associated support structures. Such vibrations would be very small in magnitude and could be easily masked by extraneous noise. In the laboratory test tanks, extraneous noise (created mainly by recirculation pumps) was extremely high. This may be the cause of the poor intake avoidance of laboratory tested fish in complete darkness.

Both the porous intake and the rope barrier should provide tactile cues to fish being entrained in darkness. As clear openings through these intakes are in the range of 13 cm to 15 cm square, most fish in the adult smelt/alewife size range should touch the structure (and take avoidance action) before passing through.

The porous intake should provide additional cues for entrained fish due to the current structure created in the immediate vicinity of the intake surface. Water flowing through the intake ports appears (on the basis of dye releases in the model) to accelerate rapidly (from approximately 5 cm/s to 15 cm/s) over the last 30 cm to 50 cm above the surface. The flow also changes direction from a largely lateral flow to a nearly vertical flow. Fish should be able to sense this change in flow rate and direction through their lateral line system. Observations of fish passing closely over the ports suggests that this is the case. A quick dart upwards and/or laterally is the usual escape response. Presumably, a similar response occurs in complete darkness. The alternating rows of open ports and refuge areas should also aid detection of accelerating intake flows by the fish, as areas of relatively "dead" water (or low velocity lateral flow) are created between the rows of intake ports.

In contrast, flow conditions in the immediate vicinity of a rope net barrier would be more uniform. The general direction of flow would be lateral, with no appreciable change in direction. Some acceleration in flow rate would occur immediately before the barrier, but due to the higher porosity of the rope barrier (53% versus 35% for PPB) the degree of acceleration would be substantially less than in the PPB intake. Also, the width of the rope barrier elements (5 cm vertical, 2.5 cm horizontal) would not likely be enough to create substantial quiescent zones between the barrier ports (openings).

Both the porous intake and the rope barrier should produce strong visual cues during daylight, providing turbidity is not excessive. Due to its vertical nature, the rope barrier is more likely to be perceived as an obstacle by the fish, causing them to divert around it, although those fish encountering the upper few metres of the barrier may swim over the intake cap. The most likely response of fish to the porous surface is to swim over the intake, possibly rising slightly above the bottom. This was the most common response in laboratory tests, although some fish changed direction and swam parallel to the intake ports/refuge channels and others diverted around the entire intake structure.

It is not clear which system would be the most successful at diverting fish in a full scale field installation. The fact that recent Ontario Hydro velocity cap intakes have been located in a large excavation (approximately 96 m in diameter by 10 m deep) is probably detrimental to fish avoidance. In order to escape completely from these intakes, fish encountering the net barrier (assuming it is attached to or near the intake cap) must swim upslope and against the intake current for at least 30 m to be clear of the excavation. This distance must be travelled after the fish loses visual contact with the rope barrier, that is, there is no reinforcement of the visual cue provided by initial contact with the barrier.

Fish crossing the porous intake must pass over two 18 m wide porous segments assuming that they cross directly over the annular intake without changing direction (Design and Development Division Report 82434). However, as the vertical components of the intake flow range from less than 1 cm/s to approximately 3 cm/s at a distance of 1 m above the intake surface (Design and Development Division Report 82650) a small vertical displacement would be sufficient to prevent fish from contacting the intake surface. Fish crossing the PPB in daylight would be provided with a visual cue (the intake surface) below them during the entire transit period. Flow rates beyond the outer edge of the porous surface are sufficiently low (<5 cm/s, Ontario Hydro Design and Development Division Report 82650) that fish leaving the immediate intake area would likely be carried away by the ambient lake currents.

The present laboratory tests have indicated that capture rates of both the porous intake and the rope net barrier increased in darkness. However, limitations of the test tank may have unduly contributed to this increased catch. In addition to the pump noise discussed earlier, the physical limitations of the tank probably increased capture rates in dark tests. The perimeter fence prevented fish from effectively escaping the capture field (area of substantial current) created by the test intakes.

Thus, any fish not continuously making directed movements (swimming against this current) would be repeatedly carried towards the intake. The depth limitation of the tank (1 m) was probably equally as important. In the field, pelagic species such as alewife and smelt tend to move toward the surface, or at least, be dispersed throughout the water column at night. The flow patterns obtained from the hydraulic model of the porous intake suggest that under static conditions (no ambient currents) the intake will withdraw water from about the 4 m to 10 m depth range. In the presence of ambient lake currents, this depth range will be compressed, with most of the water being withdrawn from the bottom few metres (W.R. Jenkner, E. Elsayed, personal communication). Thus, the behavior of pelagic fish and the withdrawal of water from near bottom should reduce the potential capture of these fish during darkness (when laboratory tests suggest they would otherwise be most susceptible to capture).

Yellow perch tend to become inactive and remain on or near the bottom in complete darkness. Presumably, perch in the immediate vicinity of a PPB intake would be vulnerable to capture at night, but their limited movement should prevent large numbers from being entrained. Also, the abundance of this species at a typical 10 m intake depth is expected to be very low.

The potential capture field of a velocity cap intake (placed in an excavation) is probably fairly similar to that of the porous intake (W.R. Jenkner, personal communication) in that most of the intake water will be withdrawn from the near-bottom region. However, as previously discussed, the excavation would probably hinder the escape of fish once they have encountered a net barrier on a velocity cap intake.

4.3 Design Parameters of the Porous Intake

The porous bottom intake was designed as a structure which would allow safe, reliable operation and reduce the capture of adult fish (primarily alewife and smelt). Accordingly, environmental criteria were important in the conceptual stages of the design. The objective was to design an intake which would provide suitable cues for fish to avoid entrapment. The location of the intake (essentially flush with the bottom in 10 m of water) should reduce the numbers of fish available for capture. Also, the vertical components of the intake flow are low enough that within a few metres of the porous surface, the longshore currents should be at least double the vertical intake flow rate. Thus, the majority of water flowing into the intake will be withdrawn from near bottom, allowing fish dispersed in the water column to pass freely over the intake. In the near field, the current inflow was designed to be heterogeneous by alternating rows of intake ports with refuge channels (or beams). The

porosity level of 35% was chosen as a reasonable compromise to limit the total size of the intake structure, yet maintain through-port velocities at levels which would allow escape of fish (alewife, smelt) in the young of the year to adult size range. Through-port velocities were chosen on the basis of cruising speeds of 3 to 6 body lengths/s for a 5 cm smelt, the expected size at the end of the first summer (A.E. Christie, personal communication). The mean through-port velocity (15 cm/s) is thus equivalent to a speed of 3 lengths/s while the maximum through-port velocity (30 cm/s) is equivalent to a speed of 6 lengths/s.

Present experiments have examined the effects of varying intake velocity on fish avoidance of a segment of the porous surface. Pumping capacity limitations of the model required the use of a 1.8 m square segment of the surface. Results in daylight indicated a progressive increase in catch of yellow perch with increased through-port velocity over the 10 cm/s to 60 cm/s range. Alewife catch also increased with velocity, although with the flush port surface, alewife were not captured below 40 cm/s and only about 10% of test fish were caught at the highest velocity (60 cm/s). With the projecting port surface, no alewife were caught in these incremental velocity tests.

Although experiments at high velocities could not be conducted with the large (3.7 m square) porous surface, the low velocity (~15 cm/s) and high velocity (~30 cm/s) rope barrier experiments provide some indication of effects from increased intake velocity on response to a larger behavioral barrier. When gross percentage capture data are considered, the higher velocity rope barrier caught slightly more smelt than the low velocity barrier (57% and 52%, respectively). With perch, the difference was more substantial. Percentage capture almost doubled (from 39% to 73%) as the result of an approximate doubling in through-port velocity. Thus, the increase in perch capture with velocity observed in the rope barrier experiments is similar to the results obtained from this species in incremental velocity experiments with the small porous surface.

Consideration of encounter data reveals a substantially different picture. For rainbow smelt, the percentage of encounters captured (daylight and twilight tests) was almost identical for low velocity and high velocity rope barrier tests (14.9% and 12.9%, respectively). For yellow perch, the percentage of encounters captured was substantially higher for the low velocity tests (low velocity = 29.2%, high velocity = 7.5%). Thus, the higher total capture values obtained in the high velocity tests were the result of much greater encounter frequencies, while the susceptibility of individual encounters to capture did not increase (actually declined). Examination of

the encounter data for the incremental velocity tests with the small porous surface provides corresponding evidence. In perch tests, both the flush port and projecting port surfaces yielded similar results. Combined percentage of encounters captured were 16.5, 21.8 and 4.1% for velocities of 10, 20 and 30 cm/s, respectively. Velocities of 40, 50 and 60 cm/s yielded values of 40.9, 43.8 and 50.0% of encounters captured. Thus it may be concluded that the susceptibility of individual perch to capture by the porous intake will not increase substantially until through-port velocities exceed 30 cm/s.

Sufficient data are not available to clearly define the velocity at which susceptibility to capture (of individual encounters) increases for alewife and smelt. Smelt were tested only up to 30 cm/s with the high velocity rope barrier and were not used in incremental velocity PPB tests. The data for alewife tested in incremental velocity tests (captures with flush ports only) suggests that the capture/encounter ratio began to rise over the 40 to 60 cm/s range but still remained very low. At velocities of 40, 50 and 60 cm/s, the percentages of encounters captured were 0.08, 0.5 and 0.4%, respectively. At each velocity, more than 800 encounters were observed. These data, combined with the better sustained and burst swimming ability of alewife and smelt (compared with perch) suggest that the susceptibility of these pelagic species to capture would not increase until through-port velocities were well above the 30 cm/s maximum expected in a porous intake field installation.

The increased encounter frequency noted at higher velocities in laboratory tests is probably largely an artifact of the test system, as the perimeter fence prevented fish from escaping the influence of the intake current. In the field, higher velocities might increase the numbers of repeat encounters to some extent, as fish must travel further from the intake to ensure a complete escape. However, the possibility also exists that fish encountering a higher intake velocity would be stimulated more strongly to take avoidance action (ie, the initial experience is more unpleasant). In conclusion, it appears that the highest velocities expected near the centre of a porous intake (<30 cm/s) should not increase the risk of capture for individual perch, alewife or smelt encountering these flows. The possibility also exists of moderately increasing overall flow rates (mean and maximum) in order to reduce the size of the intake structure. However, if such changes to the design were considered, additional high velocity experiments with alewife and smelt would be required, as present data are very limited for these species.

The size of the ports in the porous intake was chosen arbitrarily in that detailed laboratory testing of various port

sizes was not done due to the limited time available. However, there were several practical and theoretical reasons for the intake surface design chosen (by COTC task force members). A port size of approximately 13 to 14 cm was chosen to allow free passage of dead or moribund fish in the adult alewife size range as well as reduce the risk of fouling from frazil ice or detritus (eg, detached Cladophora). Use of this port size, with the ports arranged in rows (and a porosity of 35%) yielded refuge areas between the ports which were considered large enough to be utilized by adult smelt or alewife. Videotape observations suggested that many fish in laboratory encounters changed direction and followed the refuge channels (or intake ports) across the intake surface.

The dividers placed along the intake slots created square ports of approximately 13 to 14 cm. These dividers were added to reduce the probability of large fish (adult salmonids or whitefish) entering the intake, to reduce the possibility of smaller fish (smelt, alewife) being entrained through a long continuous slot, and to increase the likelihood that fish being entrained in darkness would strike the surface (and take avoidance action) prior to entrainment. It was originally intended to conduct additional experiments in late 1982/early 1983 to determine the effect of removal of the port dividers, but this was set aside in favour of the PPB/rope barrier comparisons. As the videotape records indicate that fish frequently swam near bottom, parallel to the intake ports (as well as the refuge channels), the likelihood of entrainment through the ports would seem to be higher if the dividers were removed. Hence, unless additional experiments can be conducted to determine whether the dividers can be safely eliminated, it is suggested that some form of port dividers (with spacing approximating those in the model tests) should be retained.

In relation to the size of the intake ports, comparison of present porous intake and control results provides some indication of the effect of a large change in scale of the intake openings. Controls for the incremental velocity tests consisted of a single 1.8 m square opening and controls for the fixed velocity tests consisted of a single 3.8 m square opening. In the incremental velocity tests, both total capture and capture/encounter percentages were higher for the larger control openings. In fixed velocity tests, capture percentages were higher for the control opening in alewife and perch tests, but not in smelt tests. However, all three species showed higher control capture/encounter percentages for the fixed velocity (large intake) tests. This occurred despite the fact that flow rates through the control openings were only about 1/3 those through the PPB ports (equal water volumes/time were being withdrawn but the porous surfaces had a 35% porosity and hence higher

through-port velocities). Thus the data (although limited to rather extreme changes in port size) suggest that scaling the intake design upwards (to substantially larger port sizes) would likely reduce the fish diversion efficiency of the system.

Details of the porous surface configuration (flush versus projecting intake ports) were tested in both incremental velocity (small 1.8 m surface) and fixed velocity (3.7 m surface) tests of the present study. While it was initially suspected that the projecting port intakes would yield substantially better fish protection, observed differences were quite small. In incremental velocity tests with alewife, only the flush port intake caught fish. However, captures did not begin until velocities reached 40 cm/s and even at 60 cm/s only about 10% of test fish were caught. In yellow perch incremental tests, the flush port intake caught fewer fish, especially at low velocities. Over all velocities, the flush port intake caught 73% of the perch while the projecting port intake caught 83% of the fish. The percentage of encounters resulting in capture were also similar for the two intakes (27% for flush ports, 22% for projecting ports). In the fixed velocity (large intake) tests with alewife, average captures (all light conditions) were 17.2% for flush ports and 15.0% for projecting ports. The flush port intake yielded a lower percentage of encounters captured (0.8% versus 2.4%). Capture percentages for yellow perch tested with the large porous intake indicated better performance for the projecting ports (31.9%) compared with the flush port intake (43.6%). The encounter data also favoured the projecting port veneer (51.2% of encounters captured by projecting ports, 68.5% by flush ports). It should be noted that when the December projecting port catch data (collected as part of the PPB/rope net comparison) are combined with the October data, the gross percentage capture data rises to 46.4% (higher than the flush port value). However, in this combined data set, the percentage of encounters captured is well below the value for the flush port intake.

In summary, the yellow perch data obtained from the large intake appears to favour the projecting port surface, as does the alewife data from the incremental tests. Alewife data from the large intake and perch data from the incremental tests slightly favours the flush port intake. While in balance the projecting port intake appears slightly superior (especially in dark tests) the differences are quite small. There are, however, some practical difficulties in constructing a full-scale porous intake intake with projecting ports. The projections would substantially increase the cost and complexity of intake surface construction (G. Montes, personal communication). Also, the presence of the projections would increase through-port turbulence, possibly increasing the risk of frazil ice production

(W.R. Jenkner, personal communication). Finally, it is possible that a projecting port intake would not maintain its configuration in the field, as sand and silt may accumulate in the troughs between the projections. Given these potential problems, and the small apparent gain in diversion efficiency, it is suggested that the flush port surface be used for the first field installation.

5.0 CONCLUSIONS AND RECOMMENDATIONS

1. From the incremental velocity tests with yellow perch, it may be concluded that the susceptibility to capture increased sharply as PPB intake velocities exceeded 30 cm/s. For alewife, susceptibility to capture increased only slightly over the 40 cm/s to 60 cm/s range. Hence, for field installation of a PPB intake, a mean through-port velocity of 15 cm/s, with a maximum of 30 cm/s is recommended. This should allow some margin of safety for fish encountering intake flows.
2. From the capture and encounter data obtained during incremental and fixed velocity tests, it may be concluded that differences between the two PPB intake surfaces tested (flush or projecting ports) were relatively minor. Thus, the use of either surface is recommended. Presumably, the surface configuration chosen for field application will depend on hydraulic, engineering and financial considerations.
3. Although high between-replicate variability generally prevented differences between the porous intake and the rope net barrier from being statistically significant, there was a general trend favouring the PPB intake. Hence, it is concluded that the porous intake will provide somewhat better fish protection, especially for pelagic schooling species such as alewife and smelt. In relation to its biological effectiveness, the PPB intake is recommended as the preferred alternative to a velocity cap intake with a rope net barrier. However, either system should provide better fish deterrence than a conventional velocity cap intake.

6.0 SUMMARY

1. Fish response to full-scale segments of porous intake surfaces were tested in a large laboratory model tank. Three types of experiments were conducted:
 - a) Incremental velocity tests determined the effect of increasing through-port velocity (10 cm/s to 60 cm/s) on

avoidance success of alewife and yellow perch in daylight using 1.8 m square intake surfaces (flush or projecting intake ports).

- b) Fixed velocity tests (15 cm/s) determined the response of alewife and perch to large (3.7 m square) surfaces (flush and projecting ports) in daylight, twilight and darkness.
 - c) Comparison tests determined responses of alewife, smelt and perch to the projecting port porous intake, low velocity rope barrier (15 cm/s) and high velocity rope barrier (30 cm/s) in daylight, twilight, and darkness.
2. The incremental velocity tests indicated a progressive increase in perch capture over the 10 cm/s to 60 cm/s range. At low velocities, the flush port intake caught fewer perch than the projecting port intake, but catches were similar (approximately 70%) with both intake surfaces at high velocities. Perch captures by the open (1.6 m square) control intake were substantially higher than catches of the two porous intake surfaces. Control captures of alewife were much lower, ranging from 1% at 10 cm/s to 50% at 60 cm/s. Alewife captures by the flush port intake began at 40 cm/s and only reached 10% at 60 cm/s. No alewife were captured by the projecting port surface in the incremental velocity tests. Videotape observations indicated that the susceptibility to capture for individual perch encountering the intake (both surfaces) did not increase sharply until through-port velocities exceeded 30 cm/s. Limited data for alewife suggest that the capture/encounter ratio for this species did not rise until velocities were in the 40 cm/s to 60 cm/s range and still remained low at these velocities.
3. Fixed velocity tests with alewife indicated similar capture percentages for the flush port intake (17.2%) and the projecting port intake (15.0%) over all light conditions. Capture percentages increased as light levels decreased. The percentage of alewife encounters captured by the flush port intake (0.8%) was lower than for the projecting port intake (2.4%) in daylight and twilight tests. Both total capture percentages and capture/encounter percentages for yellow perch were much higher than for alewife. The projecting port intake captured fewer perch (31.9%) than the flush port intake (43.6%). The capture/encounter data also favoured the projecting port intake (51.2% versus 68.5%). While the projecting port intake generally appeared superior to the flush port intake, differences were smaller than originally expected.

4. Comparison of the porous intake and the rope net barrier suggested that the PPB intake was more effective in reducing fish capture. Due to high between-replicate variability and limited replicate numbers, a statistically significant difference was found in only one test series (lower capture/encounter percentage for the porous intake in alewife twilight tests). There was a general trend favouring the porous intake. Of fifteen data sets collected (all light conditions for alewife, smelt and perch) the PPB results were superior in nine cases. However, as through-port velocity of a rope net barrier (installed on a velocity cap intake) would be near 30 cm/s, comparison should be made with the high velocity rope net tests. In this case, of ten data sets available, the porous intake results were superior in seven cases. Mean catch data also favoured the PPB intake. The porous intake captured 26.1% of alewife tested (16.1% if December fish in poor condition are excluded) and the low velocity rope net captured 29.5%. In smelt tests, the porous intake captured 42.8%, the low velocity rope net captured 52.0% and the high velocity rope net captured 57.0%. The porous intake caught 46.4% of perch tested, the low velocity rope net caught 39.2% and the high velocity rope net captured 73.1%. Encounter data (daylight and twilight tests) generally favour the PPB intake. Only 3.2% of alewife encountering this intake were captured, while 7.7% were captured by the low velocity rope net. The porous intake caught 5.2% of smelt encounters, the low velocity rope net caught 14.9% and the high velocity rope net caught 12.9%. Differences in perch results were less clearly defined, as 18.8% of porous intake encounters were captured, compared with 29.% by the low velocity rope net and only 7.5% by the high velocity rope net. Thus, while general trends favour the porous intake, differences were most consistent for the pelagic schooling species (alewife, smelt).

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APPENDIX 1

WATER VELOCITIES OF TEST INTAKES

A. INCREMENTAL VELOCITY TESTS - 1.8 m SQUARE INTAKE

Intake Type	Number of Pumps - Values are Mean* cm/s $\pm$ SD					
	1	2	3	4	5	6
Control (Open)	5.5 $\pm$ 1.2	9.2 $\pm$ 2.7	12.0 $\pm$ 3.4	19.2 $\pm$ 6.7	22.5**	26.8**
Flush Ports	12.5 $\pm$ 1.9	24.1 $\pm$ 6.8	36.2 $\pm$ 3.8	48.0**	59.8**	71.7**
Projecting Ports	15.5 $\pm$ 3.0	23.9 $\pm$ 7.8	37.2 $\pm$ 10.2	47.2**	58.1**	68.9**

* Means are based on 25 measurements arranged in a 5x5 grid over the intake surface.

**At high velocities, direct measurement was not possible due to vortex. Values given are extrapolations from regressions (r values from 0.978 to 0.999) based on lower velocity measurements.

B. FIXED VELOCITY TESTS - 6 PUMPS WITH 3.7 m SQUARE VENEER AND 2.7 m SQUARE (X1 m DEEP) ROPE NET BARRIER

Intake Type	Mean cm/s*	SD	Range
Control	12.2	9.3	0 - 33.6
Flush Port	17.4	13.9	0 - 52.7
Projecting Port	18.9	12.8	4.0 - 51.7
Rope Net Barrier (Low Velocity)	22.5	13.9	0 - 59.4
Rope Net Barrier (High Velocity)	30.5	14.7	0 - 53.0

* Mean for:

- control based on 25 data points
- veneers based on 36 data points each
- rope net barriers based on 24 data points each

APPENDIX 2

CAPTURE AND ENCOUNTER DATA - INCREMENTAL TESTS

A. YELLOW PERCH - CONTROL INTAKE

Rep	Pumps Running	Encounters		Captures	
		Over Ports	Total	Observed by Video	Total Post- Test Count
1	1	0	0	0	
	2	23	26	23	
	3	2	3	2	
	4				
	5				
	6				
	Total	25	29	25	25
2	1	25	25	25	
	2				
	3				
	4				
	5				
	6				
	Total	25	25	25	25
3	1	0	0	0	
	2	25	25	22	
	3	3	3	3	
	4				
	5				
	6				
	Total	28	28	25	25
All Reps		78	82	75	75

APPENDIX 2

CAPTURE AND ENCOUNTER DATA - INCREMENTAL TESTS

B. YELLOW PERCH - FLUSH PORT INTAKE

Rep	Pumps Running	Encounters		Captures	
		Over Ports	Total	Observed* by Video	Total Post-Test Count
1	1	1	5	1	1 fish escaped from veneer
	2	24	50	9	
	3	5	5	0	
	4	18	34	15	
	5	7	7	0	
	6	1	1	1	
	Total	56	102	26	25
2	1	0	0	0	
	2	4	4	3	
	3	0	4	0	
	4	25	27	13	
	5	5	6	4	
	6	0	0	0	
	Total	34	41	20	21
3	1	0	0	0	
	2	29	29	8	
	3	7	17	0	
	4	7	7	1	
	5	0	0	0	
	6	0	0	0	
	Total	43	53	9	18
All Reps		133	203	55	64

* A strong vortex at high velocities made viewing difficult. Entrainment of some fish may not have been observed.

APPENDIX 2

CAPTURE AND ENCOUNTER DATA - INCREMENTAL TESTS

C. YELLOW PERCH - PROJECTING PORT INTAKE

Rep	Pumps Running	Encounters		Captures	
		Over Ports	Total	Observed by Video*	Total Post-Test Count
1	1	25	25	0	24
	2	15	46	12	
	3	10	14	3	
	4	0	0	0	
	5	1	1	1	
	6	0	0	0	
	Total	51	86	16	
2	1	1	2	0	25
	2	1	24	1	
	3	1	33	0	
	4	23	27	16	
	5	2	2	2	
	6	2	2	1	
	Total	30	90	20	
3	1	53	77	17	21
	2	2	3	1	
	3	0	0	0	
	4	0	8	0	
	5	0	0	0	
	6	17	17	8	
	Total	72	105	26	
All Reps		153	281	62	70

* A strong vortex at high velocities made viewing difficult. Entrainment of some fish may not have been observed.

APPENDIX 2

CAPTURE AND ENCOUNTER DATA - INCREMENTAL TESTS

D. ALEWIFE - CONTROL INTAKE

Rep	Pumps Running	Encounters*		Captures	
		Over Ports	Total	Observed by Video	Total Post-Test Count
1	1	2	182 (637)	0	
	2	56	411 (766)	0	
	3	50	427	25	
	4	-			
	5	-			
	6	-			
	Total	108	1020 (1830)	25	
2	1	0	282	0	
	2	0	37	0	
	3	2	69	0	
	4	1	21	1	
	5	15	65	0	
	6	101	292 (323)	6	
	Total	119	766 (797)	7	
3	1	207	423 (647)	1	
	2	88	330 (547)	0	
	3	0	62	0	
	4	25	105	0	
	5	25	201	0	
	6	0	20	0	
	Total	345	1141 (1582)	1	
All Reps		572	2927 (4209)	33	34

* Figures are for encounters monitored in detail.
Total encounter number in brackets.

APPENDIX 2

CAPTURE AND ENCOUNTER DATA - INCREMENTAL TESTS

E. ALEWIFE - FLUSH PORT INTAKE

Rep	Pumps Running	Encounters		Captures	
		Over Ports	Total	Observed by Video	Total Post-Test Count
1	1	158	435 (766)	0	2
	2	23	278 (313)	0	
	3	97	167	0	
	4	163	394 (479)	0	
	5	66	183	2	
	6	41	106 (122)	0	
	Total	548	1563 (2030)	2	
2	1	150	370	0	4
	2	314	423 (452)	0	
	3	125	255	0	
	4	127	170 (192)	1	
	5	0	0	0	
	6	100	123 (205)	3	
	Total	816	1341 (1474)	4	
3	1	200	421 (453)	0	2
	2	475	500 (950)	0	
	3	450	500 (850)	0	
	4	304	350 (658)	0	
	5	51	62 (690)	2	
	6	46	77 (476)	0	
	Total	1562	1910 (3977)	2	
All Reps		2890	4814 (7581)	8	8

APPENDIX 2

CAPTURE AND ENCOUNTER DATA - INCREMENTAL TESTS

F. ALEWIFE - PROJECTING PORT INTAKE

Rep	Pumps Running	Encounters		Captures	
		Over Ports	Total	Observed* by Video	Total Post-Test Count
1	1	0	390 (508)	0	0
	2	43	303 (395)	0	
	3	20	324 (342)	0	
	4	2	126	0	
	5	41	178	0	
	6	25	42	0	
	Total	131	1363 (1591)	0	
2	1	11	228 (740)	0	0
	2	202	236 (638)	0	
	3	58	197 (829)	0	
	4	161	250 (600)	0	
	5	48	160 (287)	0	
	6	109	177 (376)	0	
	Total	589	1248 (3490)	0	
3	1	176	452 (803)	0	0
	2	276	451	0	
	3	275	454	0	
	4	195	300	0	
	5	155	298 (815)	0	
	6	65	80	0	
	Total	1142	2035 (2903)	0	
All Reps		1862	4646 (7984)	0	0

APPENDIX 3

FIXED VELOCITY TESTS - CAPTURE AND ENCOUNTER DATA

A. ALEWIFE

Treatment	No in Sample	No Captured	% of Sample Captured	No of Encounters	No Crossing Ports	% Encounters Captured*
Daylight Control	25 25 25 Σ 75	21 7 22 Σ 50	84.0 28.0 88.0 X̄ 66.7	116 72 263 Σ 451	86 49 176 Σ 311	18.10 (24.42) 9.72 (14.29) 8.37 (12.50) X̄ 12.06 (17.07)
Twilight Control	25 24 25 Σ 74	17 20 15 Σ 52	68.0 83.3 60.0 X̄ 70.4	57 Poor Tape 87 Σ 144	52 Poor Tape 72 Σ 124	29.82 (32.69) - 17.24 (20.83) X̄ 23.53 (26.76)
Darkness Control	25 23 25 Σ 73	20 17 14 Σ 51	80.0 73.9 56.0 X̄ 70.0			
Daylight Flush Ports	25 25 24 Σ 74	3 4 5 Σ 12	12.0 16.0 20.8 X̄ 16.3	160 387 513 Σ 1060	70 249 366 Σ 685	1.88 (4.29) 1.03 (1.61) 0.97 (1.37) X̄ 1.29 (2.42)
Twilight Flush Ports	25 19 21 Σ 65	3 0 2 Σ 5	12.0 0.0 9.5 X̄ 7.2	Poor Tape 236 292 Σ 528	Poor Tape 181 177 Σ 358	- 0.00 (0.00) 0.68 (1.13) X̄ 0.34 (0.57)
Darkness Flush Ports	24 15 19 Σ 58	13 3 2 Σ 18	54.2 20.0 10.5 X̄ 28.2			
Daylight Projecting Ports	25 25 25 Σ 75	1 6 8 Σ 15	4.0 24.0 32.0 X̄ 20.0	136 310 71 Σ 517	77 159 40 Σ 276	0.74 (1.30) 1.94 (3.77) 11.27 (20.0) X̄ 4.65 (8.36)
Twilight Projecting Ports	25 20 18 Σ 63	3 5 0 Σ 8	12.0 25.0 0.0 X̄ 12.3	39 Poor Tape 114 Σ 153	31 Poor Tape 69 Σ 100	7.69 (9.68) - 0.00 (0.00) X̄ 3.84 (4.84)
Darkness Projecting Ports	22 16 18 Σ 56	7 1 0 Σ 8	31.8 6.3 0.0 X̄ 12.7			

* Values in brackets refer to percentage of fish captured while crossing ports.

APPENDIX 3

FIXED VELOCITY TESTS - CAPTURE AND ENCOUNTER DATA

B. YELLOW PERCH

Treatment	No in Sample	No Captured	% of Sample Captured	No of Encounters	No Crossing Ports	% Encounters Captured*
Daylight Control	25 25 25 Σ 75	25 25 8 Σ 58	100.0 100.0 32.0 X̄ 77.3	25 26 8 Σ 59	25 25 8 Σ 58	100.0 (100.0) 96.15 (100.0) 100.0 (100.0) X̄ 98.72 (100.0)
Twilight Control	25 25 25 Σ 75	15 12 10 Σ 37	60.0 48.0 40.0 X̄ 49.3	26 Poor Tape Poor Tape	19 - -	57.69 (78.95) - -
Darkness Control	25 25 24 Σ 74	12 9 8 Σ 29	48.0 36.0 33.3 X̄ 39.1			
Daylight Flush Ports	25 25 25 Σ 75	2 25 5 Σ 32	8.0 100.0 20.0 X̄ 42.7	2 25 15 Σ 42	2 25 5 Σ 32	100.0 (100.0) 100.0 (100.0) 33.3 (100.0) X̄ 77.78 (100.0)
Twilight Flush Ports	25 25 20 Σ 70	14 9 0 Σ 23	56.0 36.0 0.0 X̄ 30.7	23 Poor Tape 0	21 - 0	60.86 (66.67)
Darkness Flush Ports	25 16 18 Σ 59	15 10 9 Σ 34	60.0 62.5 50.0 X̄ 57.5			
Daylight Projecting Ports	25 25 25 Σ 75	23 2 0 Σ 25	92.0 8.0 0.0 X̄ 33.3	25 15 2 Σ 42	25 11 1 Σ 37	92.0 (92.0) 13.33 (18.18) 0.00 (0.00) X̄ 35.11 (36.73)
Twilight Projecting Ports	25 23 25 Σ 73	9 8 1 Σ 18	36.0 34.8 4.0 X̄ 24.9	21 Poor Tape Poor Tape	16 - -	42.86 (56.25) - -
Darkness Projecting Ports	16 15 24 Σ 55	7 4 10 Σ 21	43.8 26.7 41.7 X̄ 37.4			

* Values in brackets refer to percentage of fish captured while crossing ports.

APPENDIX 4

COMPARISON TESTS - PROJECTING PORT VENEER VS ROPE NET BARRIER

A. ALEWIFE

TREATMENT	NO IN SAMPLE	NO CAPTURED	% OF SAMPLE CAPTURED	NO OF ENCOUNTERS	% ENCOUNTERS CAPTURED
Daylight Control	25	0	0.0	124	0.00
	25	21	84.0	128	16.41
	25	4	16.0	88	4.55
	25	16	64.0	290	5.52
	Σ 100	Σ 41	$\bar{X}$ 41.0	Σ 630	$\bar{X}$ 6.62
Twilight Control	25	7	28.0	237	2.72
	25	11	44.0	213	5.16
	25	17	68.0	365	4.66
	25	9	36.0	474	1.90
	Σ 100	Σ 44	Σ 44.0	Σ 1309	$\bar{X}$ 3.61
Darkness Control	25	8	32.0	-	-
	25	8	32.0	-	-
	25	19	76.0	-	-
	25	11	44.0	-	-
	Σ 100	Σ 46	$\bar{X}$ 46.0	-	-
Daylight Rope Net	25	0	0.0	323	0.00
	25	3	12.0	12	25.00
	21	0	0.0	70	0.00
	23	1	4.3	194	0.52
	Σ 94	Σ 4	$\bar{X}$ 4.1	Σ 599	$\bar{X}$ 6.38
Twilight Rope Net	25	6	24.0	86	6.98
	22	6	27.3	68	8.82
	25	8	32.0	70	11.43
	25	8	32.0	93	8.60
	Σ 97	Σ 28	$\bar{X}$ 28.8	Σ 317	$\bar{X}$ 8.96
Darkness Rope Net	23	14	60.9	-	-
	16	6	37.5	-	-
	25	21	84.0	-	-
	25	10	40.0	-	-
	Σ 89	Σ 51	$\bar{X}$ 55.6	-	-
Daylight Veneer	25	9	36.0	491	1.83
	25	8	32.0	343	2.33
	19	0	0.0	342	0.00
	20	10	50.0	278	3.60
	Σ 89	Σ 27	$\bar{X}$ 29.5	Σ 1454	$\bar{X}$ 1.94
Twilight Veneer	21	16	76.2	249	6.43
	20	12	60.0	258	4.65
	23	5	21.7	318	1.57
	24	15	62.5	288	5.21
	Σ 88	Σ 48	$\bar{X}$ 55.1	Σ 1113	$\bar{X}$ 4.46
Darkness Veneer	16	12	75.0	-	-
	18	13	72.2	-	-
	25	3	12.0	-	-
	25	14	56.0	-	-
	Σ 84	Σ 32	$\bar{X}$ 53.8	-	-

APPENDIX 4

COMPARISON TESTS - PROJECTING PORT VENEER VS ROPE NET BARRIER

B. SMELT

TREATMENT	NO IN SAMPLE	NO CAPTURED	% OF SAMPLE CAPTURED	NO OF ENCOUNTERS	% ENCOUNTERS CAPTURED
Daylight Control	25	12	48.0	152	7.89
	25	12	48.0	240	5.00
	23	2	8.7	22	9.09
	25	1	4.0	15	6.67
	Σ 98	Σ 27	$\bar{X}$ 27.2	Σ 429	$\bar{X}$ 7.16
Twilight Control	25	4	16.0	75	5.33
	23	7	30.4	87	8.05
	25	17	68.0	82	20.73
	26	1	3.8	115	0.87
	Σ 99	Σ 29	$\bar{X}$ 29.6	Σ 359	$\bar{X}$ 8.75
Darkness Control	25	7	28.0	-	-
	25	12	48.0	-	-
	25	20	80.0	-	-
	25	3	12.0	-	-
	Σ 100	Σ 42	$\bar{X}$ 42.0	-	-
Daylight Rope Net Low Velocity	25	11	44.0	316	3.48
	25	8	32.0	754	1.06
	25	14	56.0	63	22.22
	19	7	36.8	568	1.23
	Σ 94	Σ 40	$\bar{X}$ 42.2	Σ 1701	$\bar{X}$ 6.99
Twilight Rope Net Low Velocity	25	11	44.0	139	7.91
	25	6	24.0	10	60.00
	25	13	52.0	93	13.98
	18	7	38.9	74	9.46
	Σ 93	Σ 37	$\bar{X}$ 39.7	Σ 316	$\bar{X}$ 22.84
Darkness Rope Net Low Velocity	25	18	72.0	-	-
	25	16	64.0	-	-
	25	22	88.0	-	-
	25	19	72.0	-	-
	Σ 100	Σ 74	$\bar{X}$ 74.0	-	-
Daylight Rope Net High Velocity	25	11	44.0	729	1.51
	25	7	28.0	295	2.37
	25	18	72.0	429	4.20
	25	3	12.0	514	0.58
	Σ 100	Σ 39	$\bar{X}$ 39.0	Σ 1967	$\bar{X}$ 2.17
Twilight Rope Net High Velocity	24	10	41.7	27	37.04
	22	13	59.1	59	22.03
	25	12	48.0	42	28.57
	25	11	44.0	157	7.01
	Σ 96	Σ 46	$\bar{X}$ 48.2	Σ 285	$\bar{X}$ 23.66
Darkness Rope Net High Velocity	25	23	92.0	-	-
	23	22	95.6	-	-
	25	18	72.0	-	-
	25	19	76.0	-	-
	Σ 98	Σ 82	$\bar{X}$ 83.9	-	-
Daylight Veneer	25	10	40.0	231	4.33
	25	9	36.0	248	3.63
	19	8	42.1	306	2.61
	18	4	22.2	597	0.67
	Σ 67	Σ 31	$\bar{X}$ 35.0	Σ 1382	$\bar{X}$ 2.81
Twilight Veneer	25	11	44.0	109	10.09
	25	10	40.0	76	13.16
	25	6	24.0	160	3.75
	25	7	28.0	238	2.94
	Σ 100	Σ 34	$\bar{X}$ 34.0	Σ 583	$\bar{X}$ 7.49
Darkness Veneer	24	8	33.3	-	-
	25	14	56.0	-	-
	25	17	68.0	-	-
	25	20	80.0	-	-
	Σ 99	Σ 59	$\bar{X}$ 59.3	-	-

APPENDIX 4

COMPARISON TESTS - PROJECTING PORT VENEER VS ROPE NET BARRIER

C. YELLOW PERCH

TREATMENT	NO IN SAMPLE	NO CAPTURED	% OF SAMPLE CAPTURED	NO OF ENCOUNTERS	% ENCOUNTERS CAPTURED
Daylight Control	25	25	100.0	25	100.00
	22	18	81.8	28	64.29
	25	20	80.0	109	18.35
	25	25	100.0	36	69.44
	Σ 97	Σ 88	$\bar{X}$ 90.5	Σ 198	$\bar{X}$ 63.02
Twilight Control	25	21	84.0	31	67.74
	25	20	80.0	191	10.47
	25	12	48.0	253	4.74
	25	12	48.0	210	5.71
	Σ 100	Σ 63	$\bar{X}$ 65.0	Σ 685	$\bar{X}$ 22.17
Darkness Control	25	9	36.0	-	-
	25	16	64.0	-	-
	25	9	36.0	-	-
	25	10	40.0	-	-
	Σ 100	Σ 44	$\bar{X}$ 44.0	-	-
Daylight Rope Net Low Velocity	25	25	100.0	25	100.00
	25	25	100.0	66	37.88
	25	0	0.0	0	-
	25	1	4.0	23	4.35
	Σ 100	Σ 51	$\bar{X}$ 51.0	Σ 114	$\bar{X}$ 47.41
Twilight Rope Net Low Velocity	25	6	24.0	24	25.00
	25	5	20.0	152	3.29
	25	3	12.0	82	3.66
	21	8	38.1	66	12.12
	Σ 96	Σ 22	$\bar{X}$ 23.5	Σ 324	$\bar{X}$ 11.01
Darkness Rope Net Low Velocity	16	7	43.8	-	-
	22	8	36.4	-	-
	25	7	28.0	-	-
	25	16	64.0	-	-
	Σ 88	Σ 38	$\bar{X}$ 43.0	-	-
Daylight Rope Net High Velocity	25	21	84.0	139	15.11
	25	23	92.0	146	15.75
	25	21	84.0	315	6.67
	15	11	73.3	348	3.16
	Σ 90	Σ 76	$\bar{X}$ 83.3	Σ 948	$\bar{X}$ 10.17
Twilight Rope Net High Velocity	25	20	80.0	499	4.01
	25	17	68.0	532	3.20
	25	16	64.0	276	5.80
	24	15	62.5	233	6.44
	Σ 99	Σ 68	$\bar{X}$ 68.6	Σ 1540	$\bar{X}$ 4.86
Darkness Rope Net High Velocity	25	22	88.0	-	-
	15	8	53.3	-	-
	25	13	52.0	-	-
	25	19	76.0	-	-
	Σ 90	Σ 62	$\bar{X}$ 67.3	-	-
Daylight Veneer	25	24	96.0	48	50.00
	25	24	96.0	38	63.16
	25	12	48.0	452	2.65
	21	2	8.0	157	1.27
	Σ 98	Σ 62	$\bar{X}$ 62.0	Σ 695	$\bar{X}$ 29.27
Twilight Veneer	25	19	76.0	113	16.81
	25	17	68.0	244	6.97
	25	14	56.0	192	7.29
	25	4	16.0	199	2.01
	Σ 100	Σ 54	$\bar{X}$ 54.0	Σ 748	$\bar{X}$ 8.27
Darkness Veneer	25	12	48.0	-	-
	25	16	64.0	-	-
	25	13	52.0	-	-
	25	15	60.0	-	-
	Σ 100	Σ 56	$\bar{X}$ 56.0	-	-